ANALYSIS OF GROUND SOURCE HEAT PUMPS IN SUB-ARCTIC CONDITIONS

By

Stephen Bishop

RECOMMENDED:

Dr. Ronald Daanen

Dr. Yuri Shur

Dr. Rorik Peterson, Committee Chair

Chair, Dept. of Mechanical Engineering

ANALYSIS OF GROUND SOURCE HEAT PUMPS IN SUB-ARCTIC CONDITIONS

A

PROJECT

Presented to the Faculty

Of the University of Alaska Fairbanks

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

IN MECHANICAL ENGINEERING

By

Stephen Bishop

Fairbanks, Alaska

May 2014

Abstract

The Purpose of this project is to investigate the factors involved in the application of a ground source heat pump in subarctic conditions. This project originated with the construction of a ground source heat pump (GSHP) built at Cold Climate Housing Research Center's (CCHRC) Research Testing Facility. The GSHP built by CCHRC is an experiment to test the viability of a GSHP with different surface coverings. Specifically, this project will focus on different soil and atmospheric properties to gauge their effect on a GSHP in sub-arctic conditions. The project is primarily broken into 3 main sections which test in simulation: the effects of soil and atmospheric properties on heat flow into soil, the effects of these properties on a hypothetical GSHP and applying this to a simulation of CCHRC's GSHP. Additionally, some mitigation efforts were attempted in simulation to improve the viability of the GSHP built by CCHRC.

TABLE OF CONTENTS:

Page

Signature Page..1

Title Page..3

Abstract...5

Table of Contents...6

List of Figures..8

CHAPTER 1: BACKGROUND..9

1.1 Theory..9

1.2 Site Layout..11

1.3 Project Statement...13

CHAPTER 2:1-D TEMPERATURE MODEL..13

2.1 Definition of Model...13

2.2 Soil Properties..13

2.3 Temperature Data...15

2.4 Additional Atmospheric Properties...15

2.5 1-D Model Construction...16

2.6 Simplifications..17

2.7 Measurement Metrics...18

2.8 Parameters...18

2.9 Results..19

2.10 Observations...31

CHAPTER 3: INTEGRATION OF GSHP...32

3.1 Definition..32

3.2 Heat Load...33

3.3 Parameters...33

3.4 Metrics...33

Page

3.5
Results………34

3.6 Observations………48

CHAPTER 4: CCHRC DATA INTEGRATION……………………………………………………………………49

4.1 Introduction……49

4.2 Calibration………49

4.3 Results………51

4.4 Observations………55

CHAPTER 5: CONCLUSIONS……………………………………………………………………………………55

REFERENCES………57

LIST OF FIGURES:

Page

Figure 1:CCHRC Loop field installation……………………………………………………………………………………10

Figure 2:CCHRC GSHP Layout…………………………………………………………………………………………………12

Figure 3: Apparent Heat Capacity……………………………………………………………………………………………14

Figure 4:Simulated Air Temperature………………………………………………………………………………………15

Figure 5:N Factor temperature influence………………………………………………………………………………16

Figure 6:1D Model……17

Table 1a:Default Values for Sandy Soils…………………………………………………………………………………19

Table 1b:Default Values for Silty Soils……………………………………………………………………………………19

Table 2a: Raw Data for Sandy Soils…………………………………………………………………………………………20

Table 2b:Raw Data for Silty Soils……………………………………………………………………………………………21

Figures 7 a-c: Density Change vs Heat Metrics in Sandy Soils…………………………………………………22

Figures 8 a-c: Moisture Content vs Heat Metrics in Sandy Soils………………………………………………23

Figures 9 a-c: Freezing Factor vs Heat Metrics in Sandy Soils…………………………………………………24

Figures 10 a-c: Density Change vs Heat Metrics in Sandy Soils………………………………………………25

Figures 11a-c: Mean Annual Air Temperature vs Heat Metrics in Sandy Soils…………………………26

Figures 12 a-c: Density Change vs Heat Metrics in Silty Soils…………………………………………………27

Figures 13 a-c: Moisture Content vs Heat Metrics in Silty Soils………………………………………………28

Figures 14a-c: Freezing Factor vs Heat Metrics in Silty Soils……………………………………………………29

Figures 15 a-c: Thawing Factor vs Heat Metrics in Silty Soils…………………………………………………30

Figures 16 a-c: Mean Annual Air Temperature vs Heat Metrics in Silty Soils……………………………31

Figure 17: Basic GSHP Model…………………………………………………………………………………………………32

Table 3: Raw Data for Sandy Soils with GSHP…………………………………………………………………………35

Page

Table 4: Raw Data for Silty Soils with GSHP....36

Figures 18a-c: Density Change vs Heat Metrics in Sandy Soils with GSHP....37

Figures 19 a-c: Water Content vs Heat Metrics in Sandy Soils with GSHP....38

Figures 20 a-c: Freezing Factor vs Heat Metrics in Sandy Soils with GSHP....39

Figures 21 a-c: Thawing Factor vs Heat Metrics in Sandy Soils with GSHP....40

Figures 22 a-c: Peak Heat vs Heat Metrics in Sandy Soils with GSHP....41

Figures 23 a-c: Spread vs Heat Metrics in Sandy Soils with GSHP....42

Figures 24 a-c: Density Change vs Heat Metrics in Silty Soils with GSHP....43

Figures 25 a-c: Water Content vs Heat Metrics in Silty Soils with GSHP....44

Figures 26 a-c: Freezing Factor vs Heat Metrics in Silty Soils with GSHP....45

Figures 27 a-c: Thawing Factor vs Heat Metrics in Silty Soils with GSHP....46

Figures 27 a-c: Thawing Factor vs Heat Metrics in Silty Soils with GSHP....47

Figures 29 a-c: ½ Loop Spread vs Heat Metrics in Silty Soils with GSHP....48

Figure 30: Calibration Run....50

Table 5: CCHRC GSHP Forecast....51

Figure 31: CCHRC Loop Temperatures, Grass with No Recharge....51

Figure 32: CCHRC Loop Temperatures, Light Sand with No Recharge....52

Figure 33: CCHRC Loop Temperatures, Gravel with No Recharge....52

Figure 34: CCHRC Loop Temperatures, Gravel with 10 W/m Recharge....53

Figure 35: CCHRC Loop Temperatures, Gravel with 15 W/m Recharge....53

Figure 36: CCHRC Loop Temperatures, Gravel with 20 W/m Recharge....54

Figure 37:CCHRC Temperature Profile, Gravel with No Recharge, at 10 Yr....54

Figure 38:CCHRC Temperature Profile, Gravel with 20W/m Recharge, at 10 Yr....54

CHAPTER 1: BACKGROUND

1.1 Theory

Ground source heat pumps (GSHP) are a common technology utilized to heat structures or walkways by pulling low density heat out of the ground over a large are and improving its quality by running it though a heat pump. This technology, while prevalent in lower latitudes is scarcely used for heating in the Fairbanks area. Recently, several projects have been built in the area that utilize the technology. In particular, there is a horizontal loop field at Weller Elementary and a new system recently built at CCHRC's Research Testing Facility just south of the UAF campus.

Figure 1:CCHRC Loop field installation

While there are several types of GSHP configurations, this project will focus on a single type: a closed horizontal loop. This configuration has several benefits and disadvantages. The horizontal closed loop system can cost significantly less than other systems such as a vertical loop field, which requires drilling bore holes to depths of over a hundred feet and requires significant costs associated with geotechnical work. By contrast, a horizontal loop field requires less expensive trenching which can be done with standard earth moving equipment. The horizontal loop field will require a significant foot print to provide adequate thermal mass to heat a significant structure.

Closed- loop horizontal GSHP's get most of their thermal energy from either passive or active solar heating. Passive solar heating recharges the ground heat in the summer months through ordinary conduction with the warm summer air. Active systems attempt to collect heat and actively pump it into the ground using the loop field in a reverse direction. While an active system may greatly increase the amount of heat that may harvested during the cold winter months, they can also add significant capital and maintenance costs for running the system. The GSHP utilized by Cold Climate Housing Research Center (CCHRC) uses a passive horizontal closed loop system. As such, most of the analysis in this report will be centered around such a system.

1.2 Site Layout

CCHRC installed the project GSHP at their Research and Testing Center south of the UAF campus. The ground loop was installed in the spring of 2013 and the system was brought into operation later into the fall of the same year. Their loop field consists of 6 loops, each one hundred feet in length. A diagram of the installed loop is shown below:

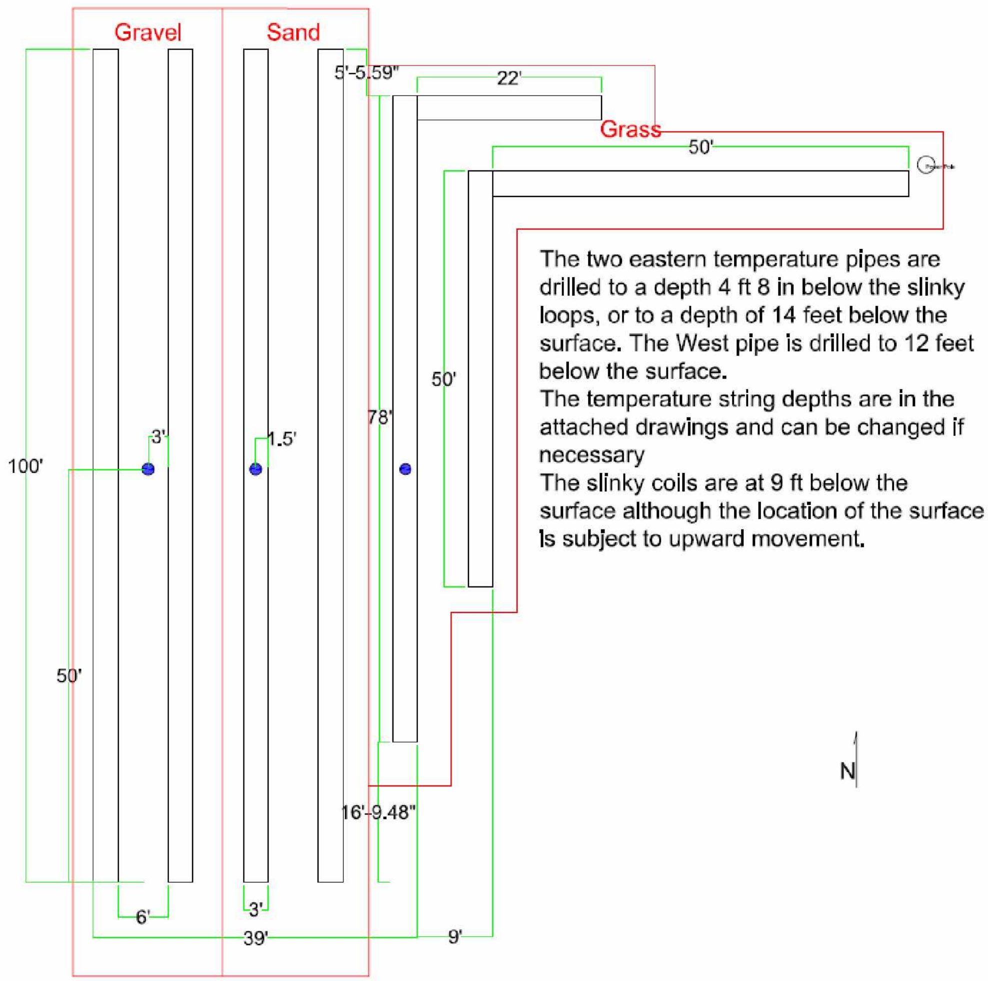


Figure 2:CCHRC GSHP Layout

These loops were paired into three different sections. These sections utilized different ground coverings: sand, gravel and grass. These coverings are an attempt to measure their physical effect on aiding or impeding heat penetration into the soil. The loop field is constructed of plastic tubing laid in a flat coiled configuration. Each trench of coil follows the full length of the trench and is then doubled back on top of itself. Each loop is the bought back to a common manifold which is fed into the heat pump. The heat pump itself is a GeoSystems RGS-W0720 heat pump. The 6-ton unit delivers hot water to a buffer tank which is then distributed hydronically to heat a segment of the CCHRC building.

1.3 Project Statement

In order to gauge the effects of various parameters involved in such a GSHP system installed at CCHRC or in a similar system, simulations of increasing complexity were created in order to model these effects. First, a basic 1-D temperature model looked at various soil conditions. Next, a 2-D model did a similar analysis with a basic GSHP system added in. The results of these two were compared. With the idea of looking at how these changes affected various aspects of GSHP performance. Finally, a simulation of the CCHRC GSHP was created and calibrated with available data. The data from the final section was analyzed to look at the long term impact of the system.

CHAPTER 2:1-D TEMPERATURE MODEL

2.1 Definition of Model

As part of this study, several computer based models were utilized to simulate the effects of heat flow into and out the ground over time. This section will focus on a simple 1-dimensional analysis of a soil column. This simple model will provide a baseline for parameterizing various aspects of soil and atmospheric conditions and how they relate to heat flow through the soil column. Several soil properties, including density, moisture content, thermal conductivity heat capacity were parameterized. Additionally with atmospheric factors such as annual temperature swings as well as surface "N" factors that may influence soil surface temperature were also studied to see their influence.

2.2 Soil Properties

To accurately portray a soil column several properties were need. The soil was defined primarily by: density, thermal conductivity, heat capacity & moisture content.

Density: Density is highly dependent on the type of soil such as mineral soil versus an organic based soil.

Thermal Conductivity: Conductivity was derived from Kersten's Equations (1949):

$$K_{sfSAND} = 0.076 \cdot 10^{[0.013 \cdot \square]} + 0.032 \cdot 10^{[0.0146 \cdot \square]} \cdot W \quad \textbf{(1a)}$$

$$K_{suSAND} = (0.7 \cdot \log(W) + 0.4) \cdot 10^{[0.01 \cdot \square]} \quad \textbf{(1b)}$$

$$K_{sfSILT} = 0.01 \cdot 10^{[0.022 \cdot \square]} + 0.085 \cdot 10^{[0.008 \cdot \square]} \cdot W \quad \textbf{(1c)}$$

$$K_{suSILT} = (0.9 \cdot \log(W) - 0.2) \cdot 10^{[0.01 \cdot \square]} \quad \textbf{(1d)}$$

In these equations, K is thermal conductivity presented in [Btu·in/ft^2·h·°F] whose values were converted into [Watts/ m·K] for use in the model. W in these equations is the volumetric water content and ρ is the dry soil density. These equations base conductivity in certain soil types correlating several factors such as density, moisture content and weather the soil is frozen or unfrozen. While these equations are a bit complicated they provided a sensible thermal conductivity at various moisture content levels.

Heat Capacity: Heat capacity as the name implies is the amount of energy required to heat a chunk of soil. This model used an apparent heat capacity to model both the thawed, frozen as well as the heat of fusion required to freeze the moisture in the soil. An example of this temperature dependent function can be seen below:

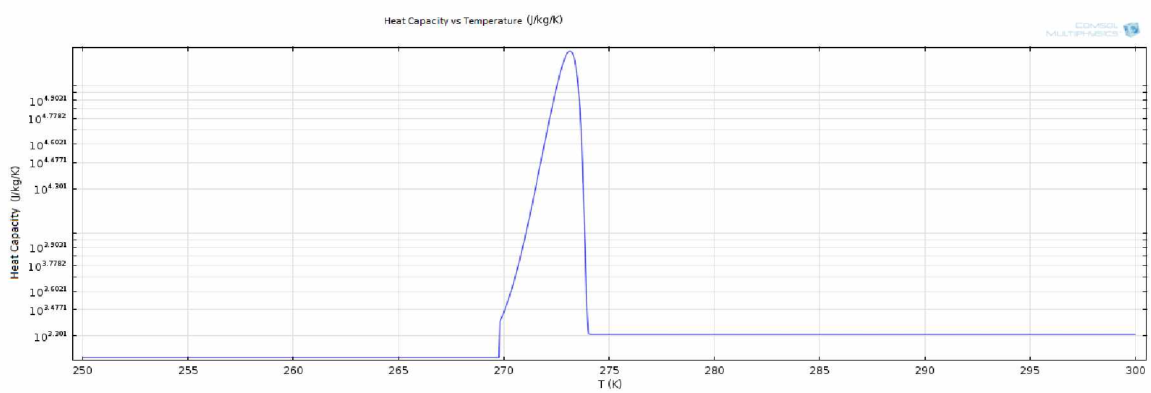


Figure 3: Apparent Heat Capacity

The spike in the apparent heat capacity was calculated from the moisture content as well as the latent heat in freezing water. The shape of the pulse is derived from a probabilistic curve that attempts to minimalize errors caused by the time stepping in the simulation.

Moisture Content: Moisture content plays a huge role in how the soil acts around freezing and subfreezing temperatures. Large water contents in soil can cause drastic changes in volume and soil stability. For the purposes of this project, the largest influence will be how the latent heat is able to absorb massive amounts of heat as well as its effect on changing thermal conductivity of both frozen and unfrozen soils. This will drastically change how the soil reacts in a cyclic basis.

2.3Temperature Data:

For this basic model, temperature data was acquired from Western Region Climate Center's (WRCC) online repository. For a baseline, the data from Fairbanks International Airport's weather station was used. This data set was chosen for its consistency as well as close proximity to the project site. This temperature data contains a 30 year average. When averaged over thirty years, the temperature creates a near perfect sinusoid. That temperature provided a baseline yearly model for testing a predicting temperature profiles in a simulated soil column.

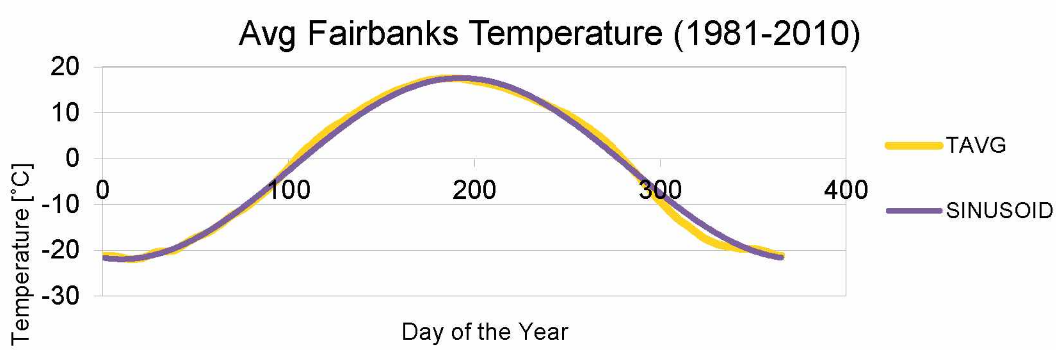


Figure 4:Simulated Air Temperature

Temperature data from the project site was also utilized. This will be seen in a later section for calibration of the model to the project location.

2.4 Additional Atmospheric Properties

To emulate the effects of insulation of the surface during the winter and irradiance in the summer months, an N factor was utilized to estimate these effects. An exaggerated example of this is shown below:

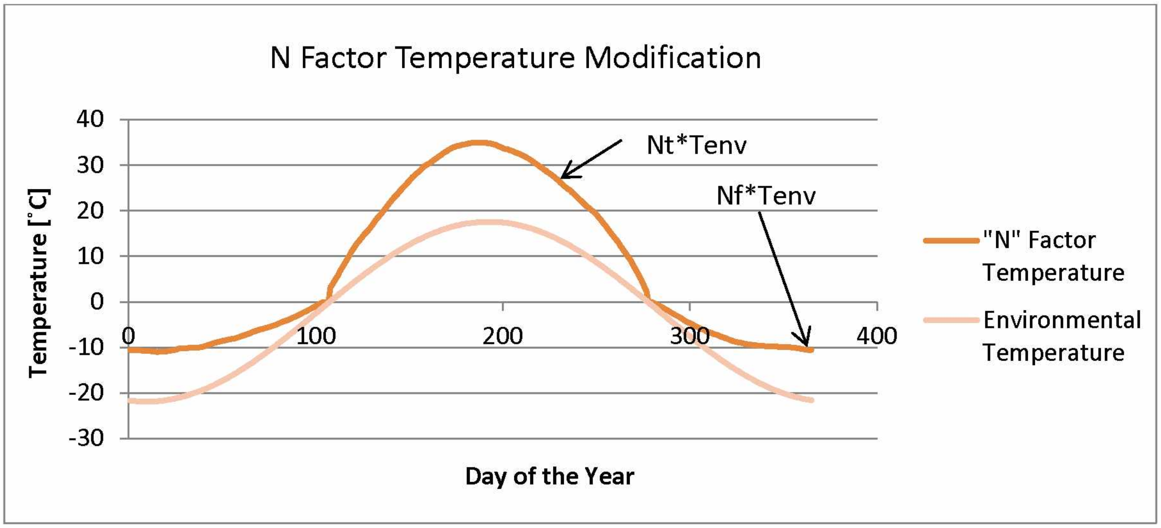


Figure 5:N Factor temperature influence

While the method is not exact, it does give a good approximation for different ground coverings. Along with the "N" factors, mean annual air temperature was varied to look at its effect on the temperature regime within the soil column.

2.5 1-D Model Construction:

The one dimensional heat flow model was produced with PDE simulation solver, COMSOL Multiphysics. Using the program's built in modeler a simple rectangular block was modeled to represent a soil column.

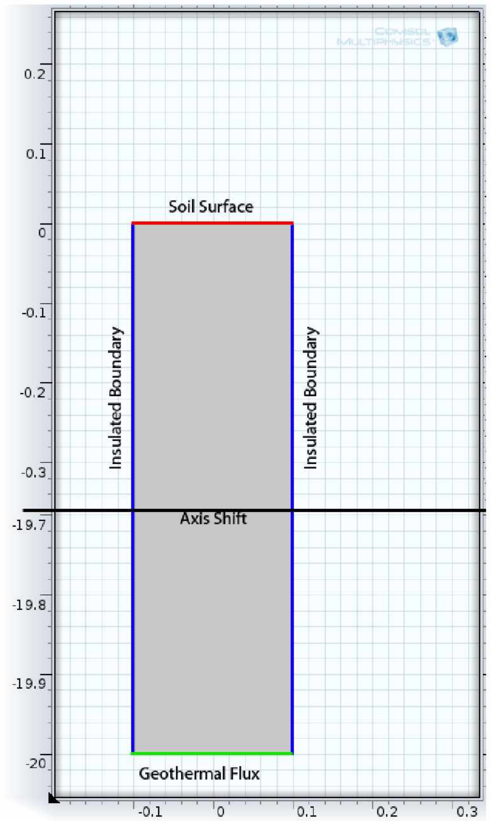


Figure 6:1D Model

To represent the effects of one dimensional heat flow the sides of the model were treated as insulation. The top surface acted as the soil surface and had a forced sinusoidal temperature function applied to it. The bottom of the model extended to 20 meters of soil. The length provided enough depth for a full active layer to develop in the soil without influence from the truncated soil column. The bottom of the model had a small forced flux of 5 mW/m^2. This simulates the minuscule geothermal heat flux.

2.6 Simplifications:

This model also makes several simplifications both in the interest of ease of use and ability of the software to accurately portray.

1. The volume is defined as constant. While freezing soil may expand or heave significantly. It is out of capability of the software to accurately portray this phenomenon. This should not significantly alter the results of the simulation.
2. There is assumed to be zero water flow within the model. While subterranean water flow may carry significant amount of heat laterally. The project site that this is aimed at does not have significant amounts of water flow and was not considered in this simulation.
3. Surface temperature values are based off averages and do not accurately portray any “typical” year. However this simplification allows the model to be extrapolated over the course many years to see what the steady state of the system should be.

Simulations were held over the course of 20 years. The first 15 years were used to allow the model to equilibrate and reach pseudo state. The data was then taken from the remaining five. Initial conditions for the active layer were estimated using temperature data from the original project site.

2.7 Measurement Metrics:

To measure the potential effects of soil properties and environmental change several metrics were utilized and recorded for each simulation run. Samples for each metric were taken from the end of the simulation run.

<u>Temperature at 1 meter:</u> The temperature, averaged from years 15 to 20 in each simulation, was recorded.

<u>Max/Min Heat Flux:</u> The heat flux, recorded as a solid cut through the model at 0.2m was taken. The below graphs show the maximum heat flux which represented the peak heat flux upwards during the winter months. Conversely, the minimum downward heat flux was measured for the summer months. This reading gave a good look at how fast the heat flow was able to penetrate the surface as well as flow through the soil.

<u>Depth of Freeze:</u> The maximum depth of freeze was recorded after each simulation run. This gave the approximate depth of the active layer in the soil. Under some conditions this actually showed the formation of permafrost. Though this still worked as a metric since it show the rate at which the expansion occurred.

2.8 Parameters:

Several soil and atmospheric properties were parameterized for this section. This included the bulk soil properties of dry soil density, volumetric water content and sandy vs silty soils. Additionally, the atmospheric and surface properties including freezing and thawing "N" factor and the mean annual air temperature.

For each soil type, a default set of parameters was chosen. These set points gave a good start point for each parametric run. The thermal diffusivity values are dependent on density, water content and dry heat capacity. The complete set of values is displayed below:

Soil Properties					Environmental Factors		
Soil Type	Independent Parameters		Thermal Diffusivity		Surface 'N' Factors		
Sand / Gravel	ρ [kg/m^3]	W	Frozen[m^2/s]	Unfrozen[m^2/s]	Freezing	Thawing	MAAT [°C]
	1400	30.00%	1.39E-06	5.42E-07	1	1	-2.1

Table 1a:Default Values for Sandy Soils

Soil Properties					Environmental Factors		
Soil Type	Independent Parameters		Thermal Diffusivity		Surface 'N' Factors		
Silt / Clay	ρ [kg/m^3]	W	Frozen[m^2/s]	Unfrozen[m^2/s]	Freezing	Thawing	MAAT [°C]
	1400	30.00%	7.27E-04	3.20E-04	1	1	-2.1

Table 1b:Default Values for Silty Soils

2.9 RESULTS:

Table 2a: Raw Data for Sandy Soils

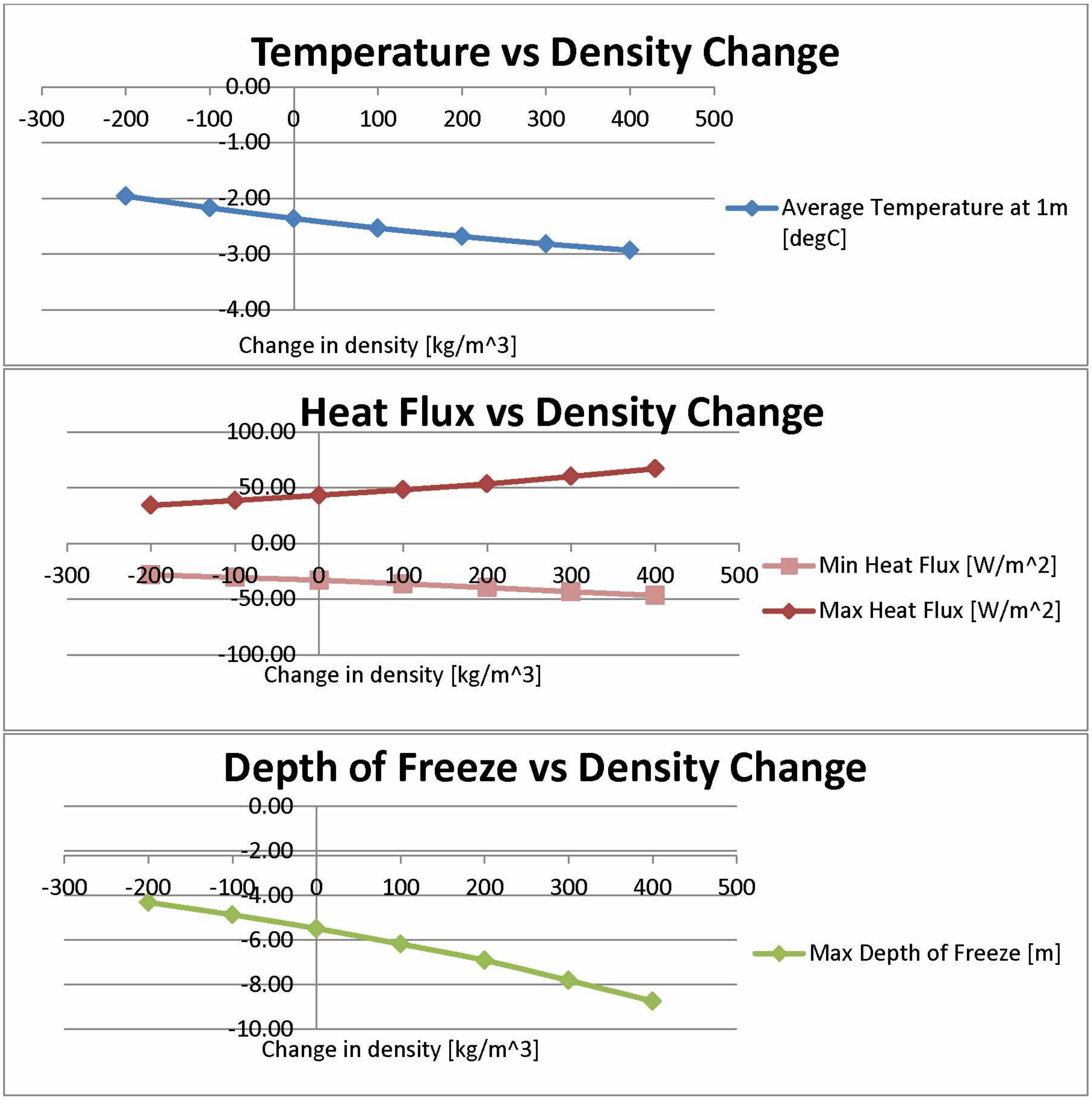
Soil Properties					Environmental Factors				Simulation Results			
Soil Type	Independent Parameters		Thermal Diffusivity		Surface 'N' Factors					Heat Flux [W/m^2]		
Sand / Gravel	ρ [kg/m^3]	W	Frozen[m^2/s]	Unfrozen[m^2/s]	Freezing	Thawing	MAAT [°C]	DELTA	1m Avg [°C]	Max	Min	Depth of Freeze [m]
	1800	30.00%	2.49E-06	7.50E-07	1	1	-2.1	400	-2.93	66.90	-46.79	-8.74
	1700	30.00%	2.14E-06	6.88E-07	1	1	-2.1	300	-2.82	59.97	-43.37	-7.81
	1600	30.00%	1.85E-06	6.33E-07	1	1	-2.1	200	-2.68	53.29	-39.74	-6.91
	1500	30.00%	1.60E-06	5.85E-07	1	1	-2.1	100	-2.53	48.03	-36.26	-6.18
	1400	30.00%	1.39E-06	5.42E-07	1	1	-2.1	0	-2.36	43.15	-33.08	-5.49
	1300	30.00%	1.22E-06	5.06E-07	1	1	-2.1	-100	-2.17	38.43	-30.66	-4.87
	1200	30.00%	1.07E-06	4.75E-07	1	1	-2.1	-200	-1.96	34.07	-28.28	-4.31
	1400	70.00%	1.99E-06	3.54E-07	1	1	-2.1	40.00%	-3.78	97.00	-55.36	-6.16
	1400	60.00%	1.89E-06	3.87E-07	1	1	-2.1	30.00%	-3.54	83.35	-50.31	-6.06
	1400	50.00%	1.76E-06	4.28E-07	1	1	-2.1	20.00%	-3.24	69.88	-45.64	-5.93
	1400	40.00%	1.60E-06	4.79E-07	1	1	-2.1	10.00%	-2.86	56.45	-39.61	-5.76
	1400	30.00%	1.39E-06	5.42E-07	1	1	-2.1	0.00%	-2.36	43.15	-33.08	-5.49
	1400	20.00%	1.12E-06	6.22E-07	1	1	-2.1	-10.00%	-1.71	29.71	-26.12	-4.98
	1400	10.00%	7.25E-07	6.99E-07	1	1	-2.1	-20.00%	-0.78	16.34	-17.20	-3.66
	1400	30.00%	1.39E-06	5.42E-07	1	1	-2.1	0	-2.36	43.15	-33.08	-5.49
	1400	30.00%	1.39E-06	5.42E-07	0.9	1	-2.1	-0.1	-1.76	40.91	-32.84	-5.09
	1400	30.00%	1.39E-06	5.42E-07	0.8	1	-2.1	-0.2	-1.19	38.30	-32.63	-4.65
	1400	30.00%	1.39E-06	5.42E-07	0.7	1	-2.1	-0.3	-0.63	35.82	-32.23	-4.16
	1400	30.00%	1.39E-06	5.42E-07	0.6	1	-2.1	-0.4	-0.08	33.26	-31.92	-3.57
	1400	30.00%	1.39E-06	5.42E-07	0.5	1	-2.1	-0.5	0.50	30.24	-31.42	-2.84
	1400	30.00%	1.39E-06	5.42E-07	1	2	-2.1	1	1.20	45.28	-47.55	-3.91
	1400	30.00%	1.39E-06	5.42E-07	1	1.8	-2.1	0.8	0.45	44.54	-44.52	-4.31
	1400	30.00%	1.39E-06	5.42E-07	1	1.6	-2.1	0.6	-0.27	43.89	-41.54	-4.63
	1400	30.00%	1.39E-06	5.42E-07	1	1.4	-2.1	0.4	-0.98	43.63	-38.83	-4.91
	1400	30.00%	1.39E-06	5.42E-07	1	1.2	-2.1	0.2	-1.67	43.36	-36.06	-5.20
	1400	30.00%	1.39E-06	5.42E-07	1	1	-2.1	0	-2.36	43.15	-33.08	-5.49
	1400	30.00%	1.39E-06	5.42E-07	1	1	2.0	4.1	0.57	42.40	-33.22	-3.50
	1400	30.00%	1.39E-06	5.42E-07	1	1	1.0	3.1	-0.15	42.71	-33.34	-4.12
	1400	30.00%	1.39E-06	5.42E-07	1	1	0.0	2.1	-0.86	42.73	-33.29	-4.61
	1400	30.00%	1.39E-06	5.42E-07	1	1	-1.0	1.1	-1.56	42.98	-33.34	-5.04
	1400	30.00%	1.39E-06	5.42E-07	1	1	-2.1	0	-2.36	43.15	-33.08	-5.49
	1400	30.00%	1.39E-06	5.42E-07	1	1	-3.0	-0.9	-2.97	43.02	-32.98	-5.81
	1400	30.00%	1.39E-06	5.42E-07	1	1	-4.0	-1.9	-3.68	43.36	-33.21	-6.14

(shaded cell) is the variable being parameterized in the simulation run.

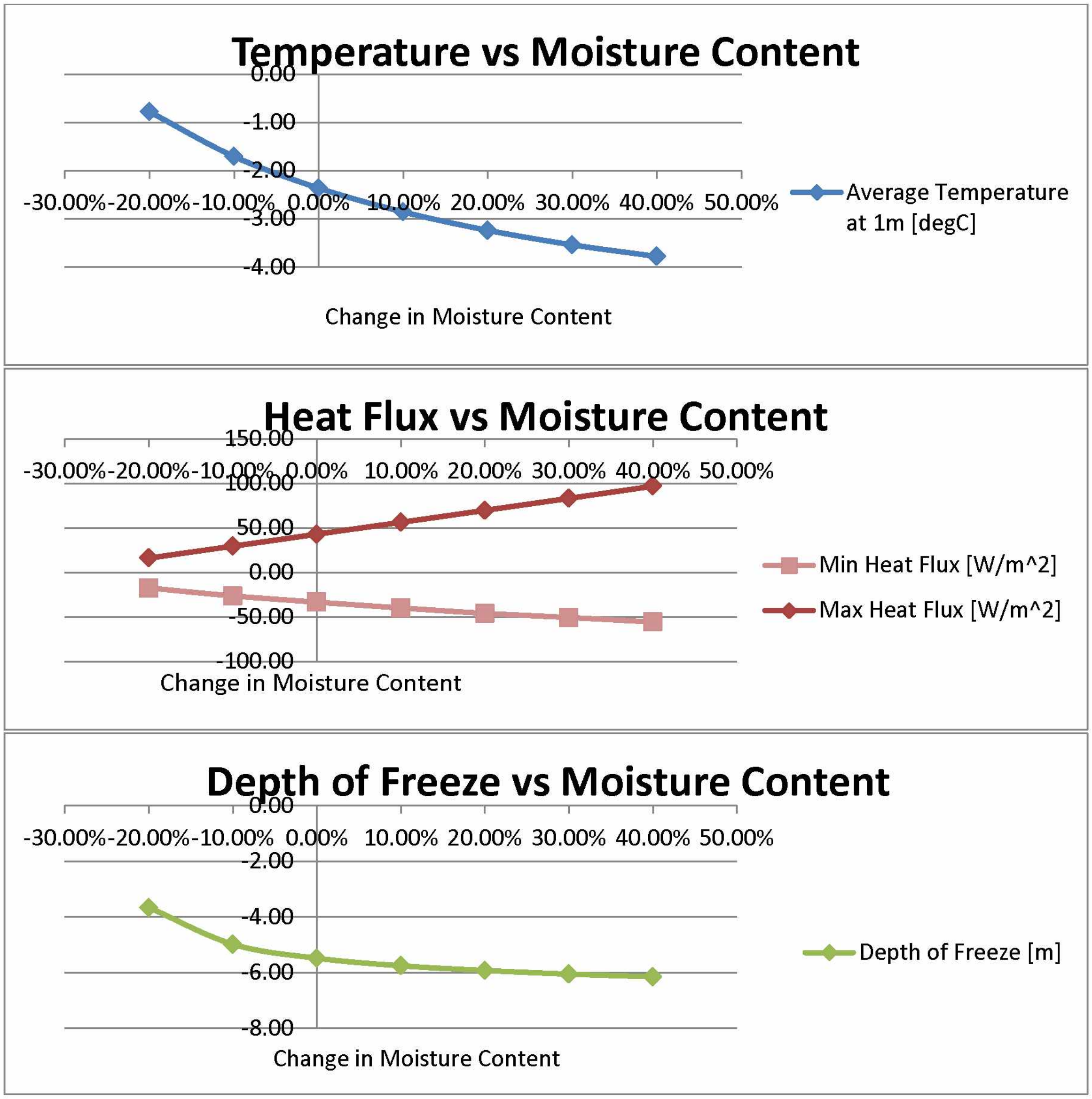
Soil Properties					Environmental Factors				Simulation Results			
Soil Type	Independent Parameters		Thermal Diffusivity		Surface 'N' Factors					Heat Flux [W/m^2]		
Silt / Clay	ρ [kg/m^3]	W	Frozen[m^2/s]	Unfrozen[m^2/s]	Freezing	Thawing	MAAT [°C]	DELTA	1m Avg [°C]	Max	Min	Depth of Freeze [m]
	1800	30.00%	1.24E-03	5.68E-04	1	1	-2.1	400	-2.05	48.54	-39.92	-5.69
	1700	30.00%	1.08E-03	4.92E-04	1	1	-2.1	300	-2.04	44.96	-36.86	-5.34
	1600	30.00%	9.43E-04	4.26E-04	1	1	-2.1	200	-2.03	41.61	-34.13	-5.02
	1500	30.00%	8.26E-04	3.69E-04	1	1	-2.1	100	-2.03	38.85	-31.36	-4.73
	1400	30.00%	7.27E-04	3.20E-04	1	1	-2.1	0	-2.03	36.19	-29.01	-4.48
	1300	30.00%	6.41E-04	2.77E-04	1	1	-2.1	-100	-2.04	33.70	-26.72	-4.24
	1200	30.00%	5.66E-04	2.40E-04	1	1	-2.1	-200	-2.04	31.52	-24.51	-4.02
	1400	70.00%	1.36E-03	2.99E-04	1	1	-2.1	40%	-3.26	81.17	-50.85	-5.02
	1400	60.00%	1.28E-03	3.22E-04	1	1	-2.1	30%	-3.05	69.99	-45.64	-4.95
	1400	50.00%	1.19E-03	3.48E-04	1	1	-2.1	20%	-2.78	58.77	-40.46	-4.83
	1400	40.00%	1.08E-03	3.78E-04	1	1	-2.1	10%	-2.45	47.44	-35.07	-4.70
	1400	30.00%	9.34E-04	4.11E-04	1	1	-2.1	0%	-2.03	36.19	-29.01	-4.48
	1400	20.00%	7.45E-04	4.39E-04	1	1	-2.1	-10%	-1.51	24.88	-22.13	-4.12
	1400	10.00%	4.83E-04	4.17E-04	1	1	-2.1	-20%	-0.87	13.79	-13.63	-3.46
	1400	30.00%	7.27E-04	3.20E-04	1	1	-2.1	0	-2.03	36.19	-29.01	-4.48
	1400	30.00%	7.27E-04	3.20E-04	0.9	1	-2.1	-0.1	-1.47	34.15	-28.70	-4.12
	1400	30.00%	7.27E-04	3.20E-04	0.8	1	-2.1	-0.2	-0.94	32.28	-28.25	-3.75
	1400	30.00%	7.27E-04	3.20E-04	0.7	1	-2.1	-0.3	-0.42	29.96	-28.25	-3.31
	1400	30.00%	7.27E-04	3.20E-04	0.6	1	-2.1	-0.4	0.09	27.93	-27.80	-2.77
	1400	30.00%	7.27E-04	3.20E-04	0.5	1	-2.1	-0.5	0.63	25.27	-27.72	-2.18
	1400	30.00%	7.27E-04	3.20E-04	1	2	-2.1	1	1.37	38.47	-41.58	-2.93
	1400	30.00%	7.27E-04	3.20E-04	1	1.8	-2.1	0.8	0.65	37.49	-39.18	-3.26
	1400	30.00%	7.27E-04	3.20E-04	1	1.6	-2.1	0.6	-0.05	37.22	-36.71	-3.62
	1400	30.00%	7.27E-04	3.20E-04	1	1.4	-2.1	0.4	-0.73	36.80	-34.46	-3.93
	1400	30.00%	7.27E-04	3.20E-04	1	1.2	-2.1	0.2	-1.38	36.26	-31.55	-4.20
	1400	30.00%	7.27E-04	3.20E-04	1	1	-2.1	0	-2.03	36.19	-29.01	-4.48
	1400	30.00%	7.27E-04	3.20E-04	1	1	2.0	4.1	0.72	35.59	-29.10	-2.65
	1400	30.00%	7.27E-04	3.20E-04	1	1	1.0	3.1	0.04	36.03	-29.16	-3.19
	1400	30.00%	7.27E-04	3.20E-04	1	1	0.0	2.1	-0.63	35.99	-29.10	-3.66
	1400	30.00%	7.27E-04	3.20E-04	1	1	-1.0	1.1	-1.28	35.89	-29.10	-4.07
	1400	30.00%	7.27E-04	3.20E-04	1	1	-2.1	0	-2.03	36.19	-29.01	-4.48
	1400	30.00%	7.27E-04	3.20E-04	1	1	-3.0	-0.9	-2.60	36.38	-29.04	-4.76
	1400	30.00%	7.27E-04	3.20E-04	1	1	-4.0	-1.9	-3.28	36.50	-28.80	-5.06
		is the variable being parameterized in the simulation run.										

Table 2b:Raw Data for Silty Soils

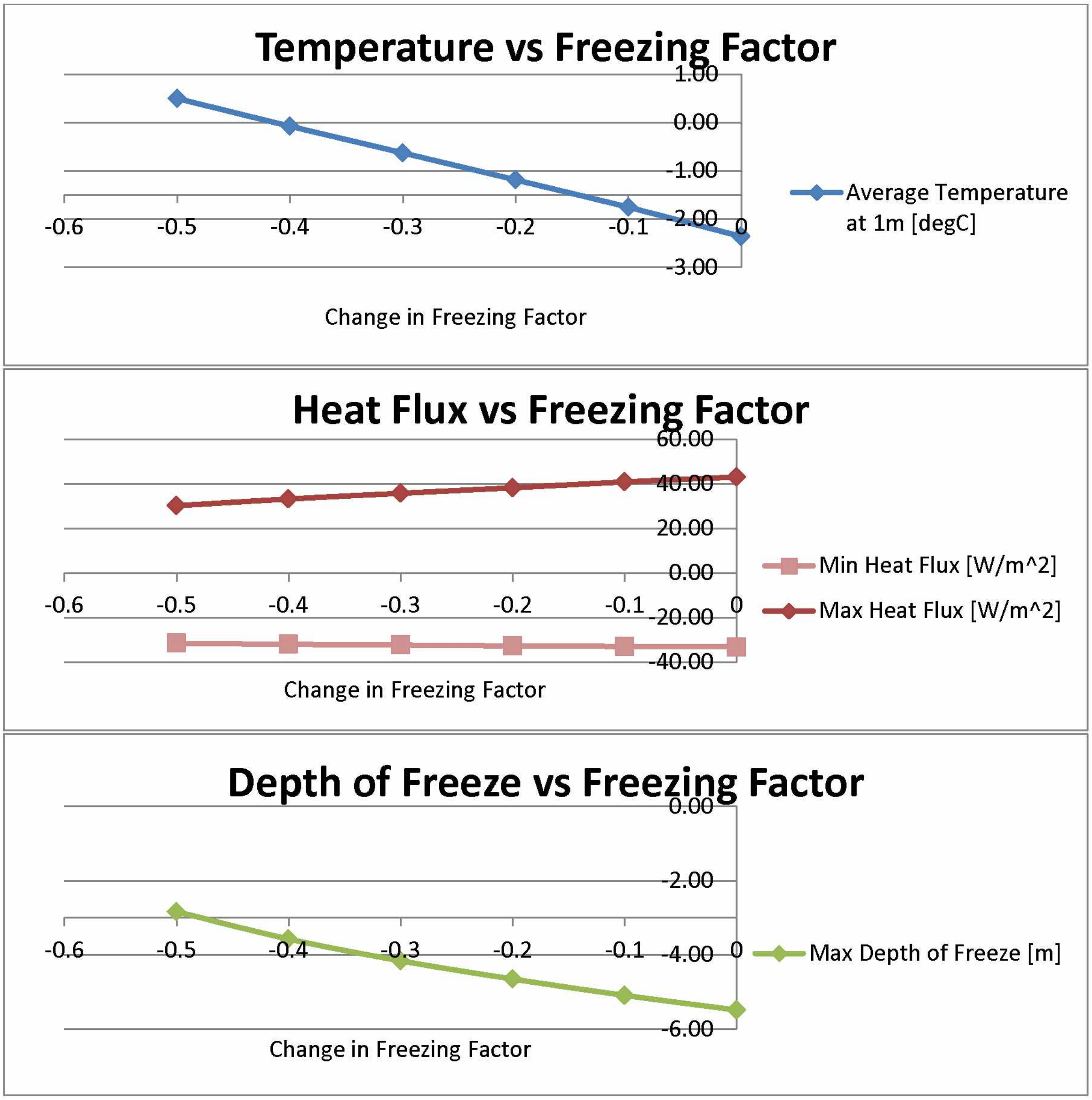
This first set of graphs displays varied soil properties for homogeneous sandy based soils:



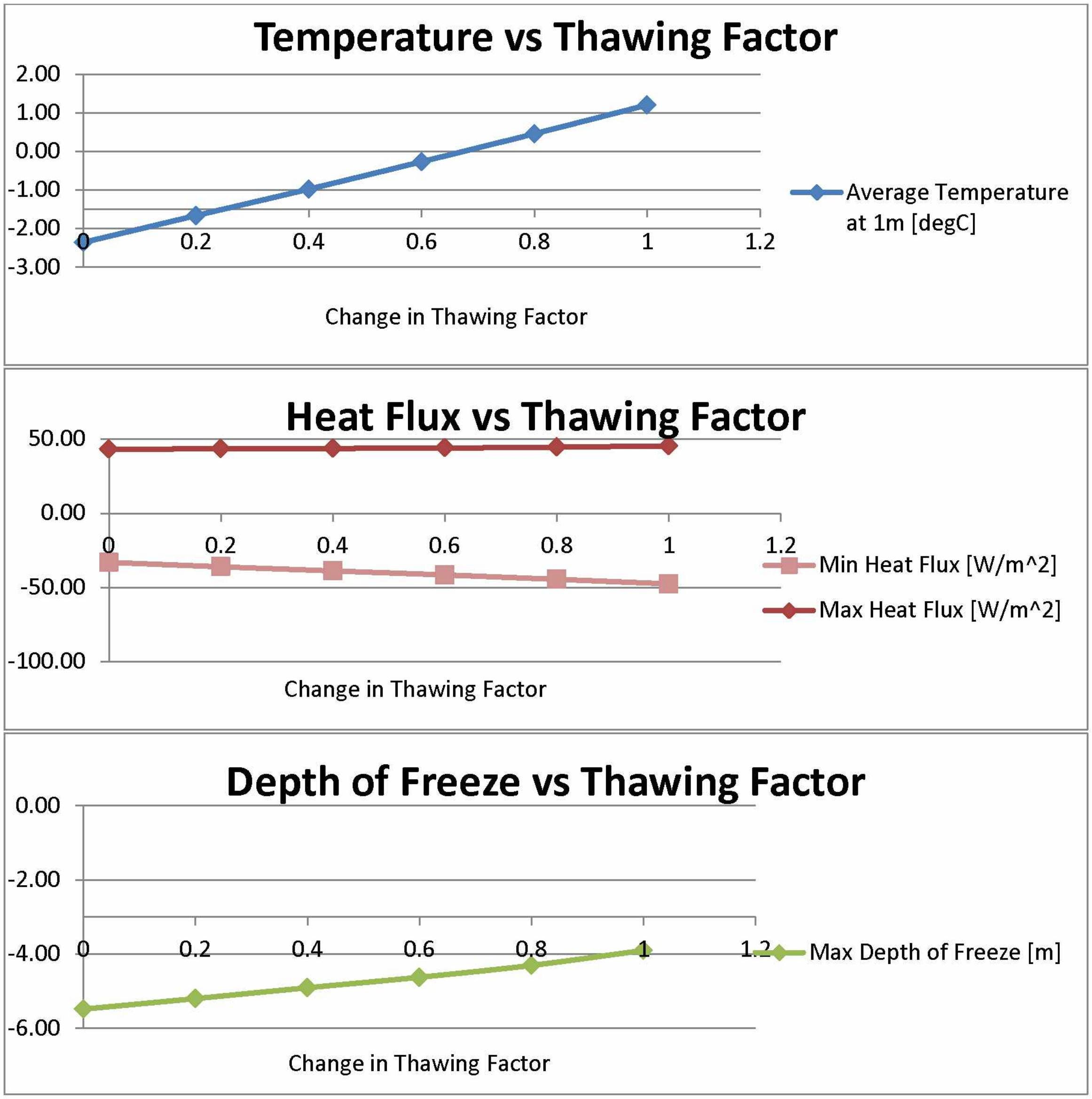
Figures 7 a-c: Density Change vs Heat Metrics in Sandy Soils



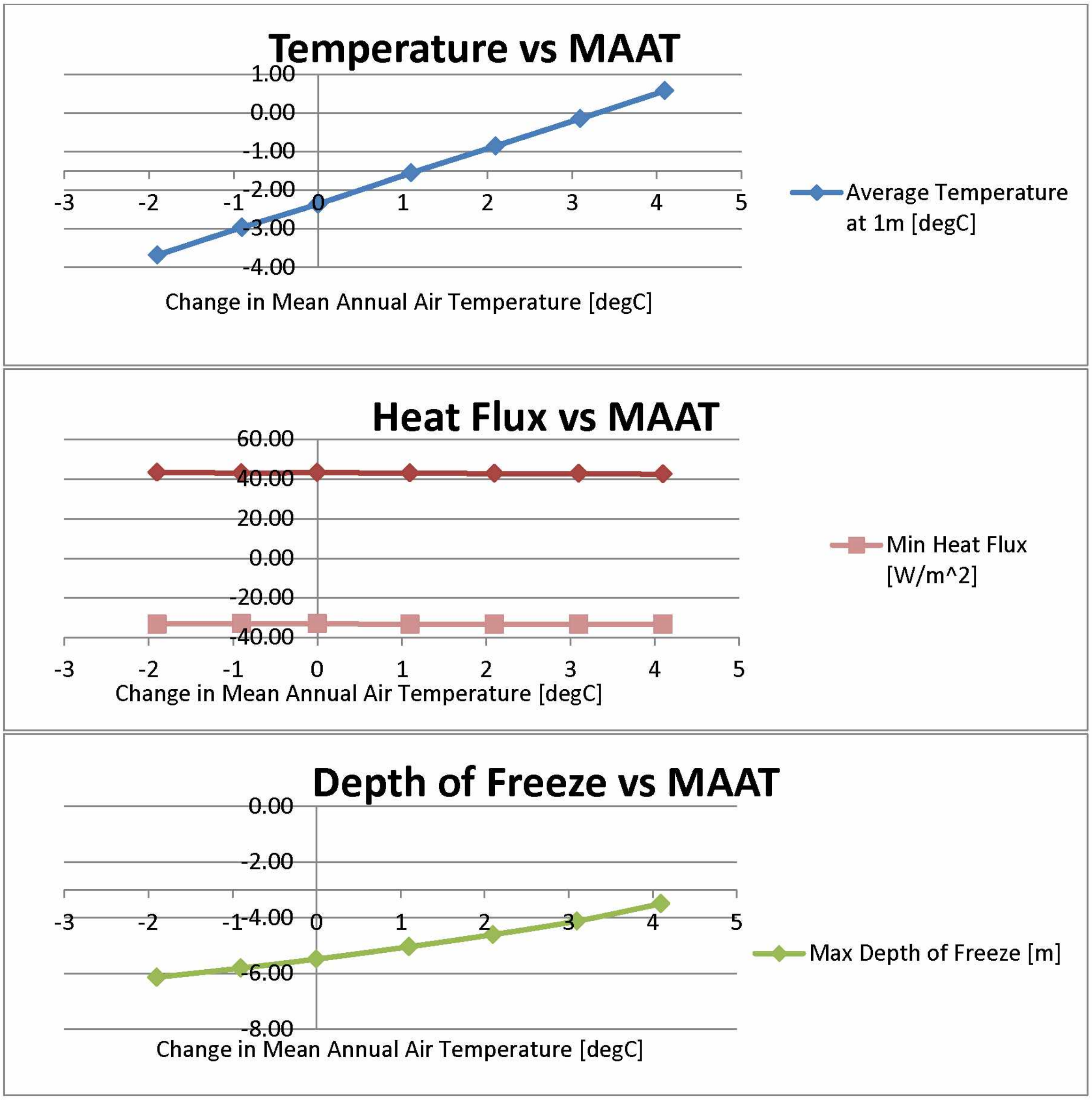
Figures 8 a-c: Moisture Content vs Heat Metrics in Sandy Soils



Figures 9 a-c: Freezing Factor vs Heat Metrics in Sandy Soils

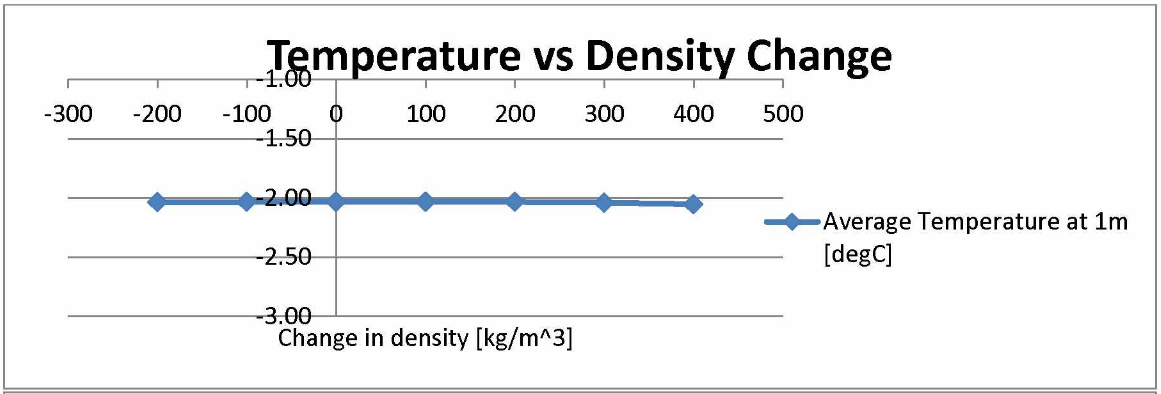


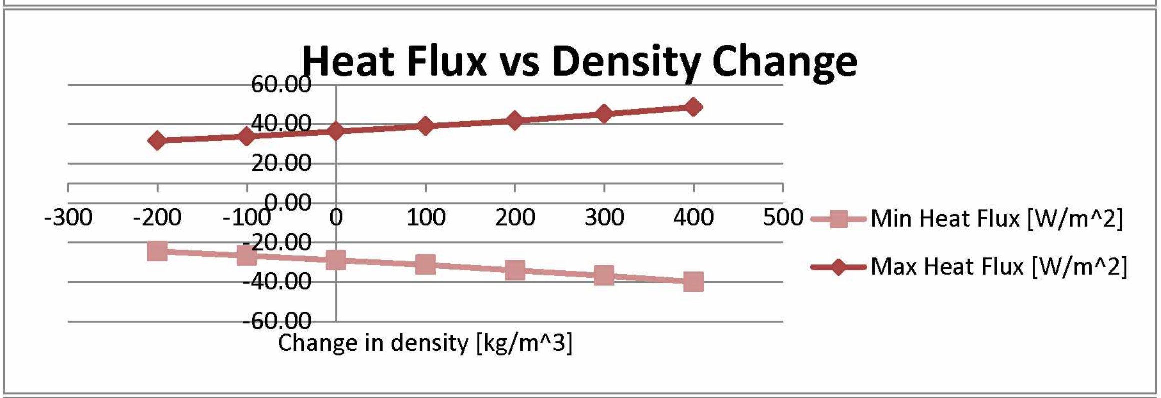
Figures 10 a-c: Density Change vs Heat Metrics in Sandy Soils

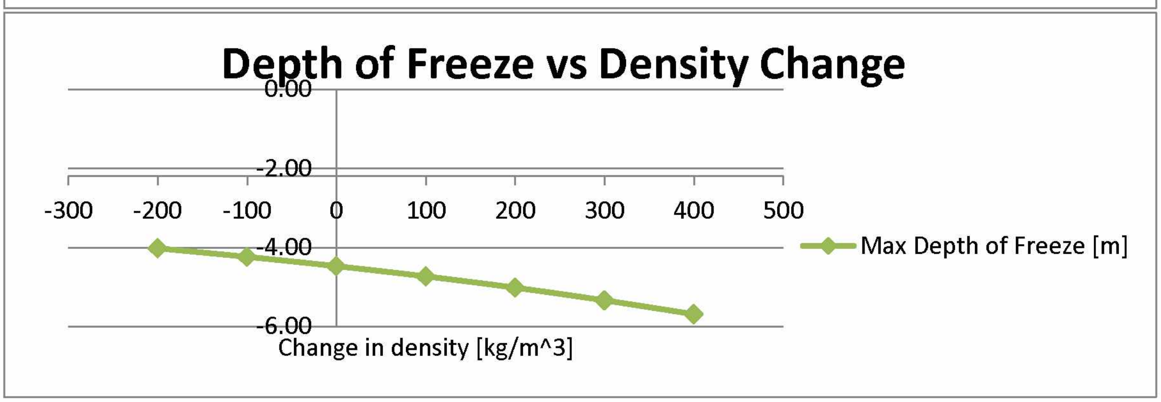


Figures 11a-c: Mean Annual Air Temperature vs Heat Metrics in Sandy Soils

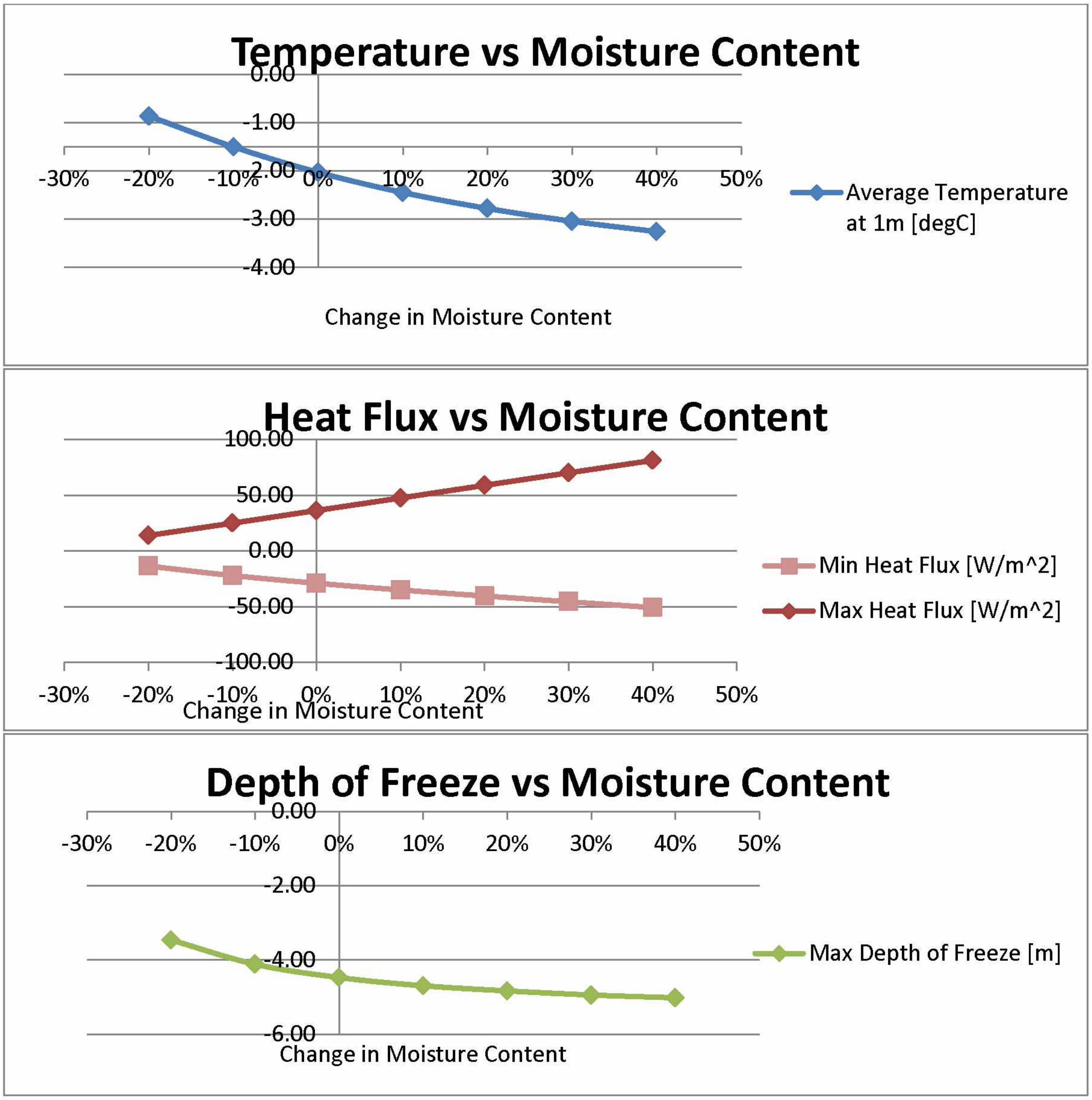
The next set of graphs is for the silt based soils using the same parameter settings:



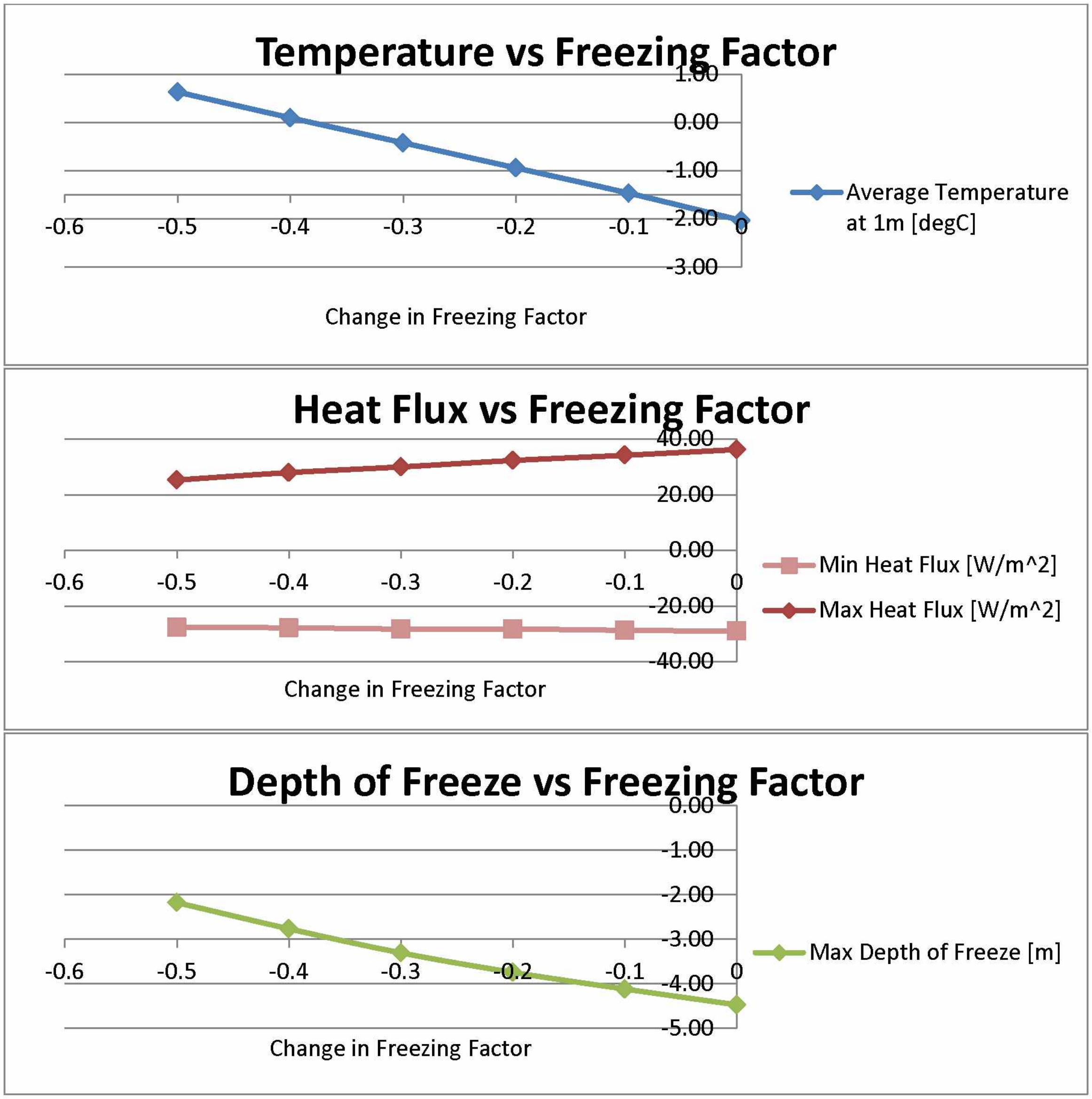




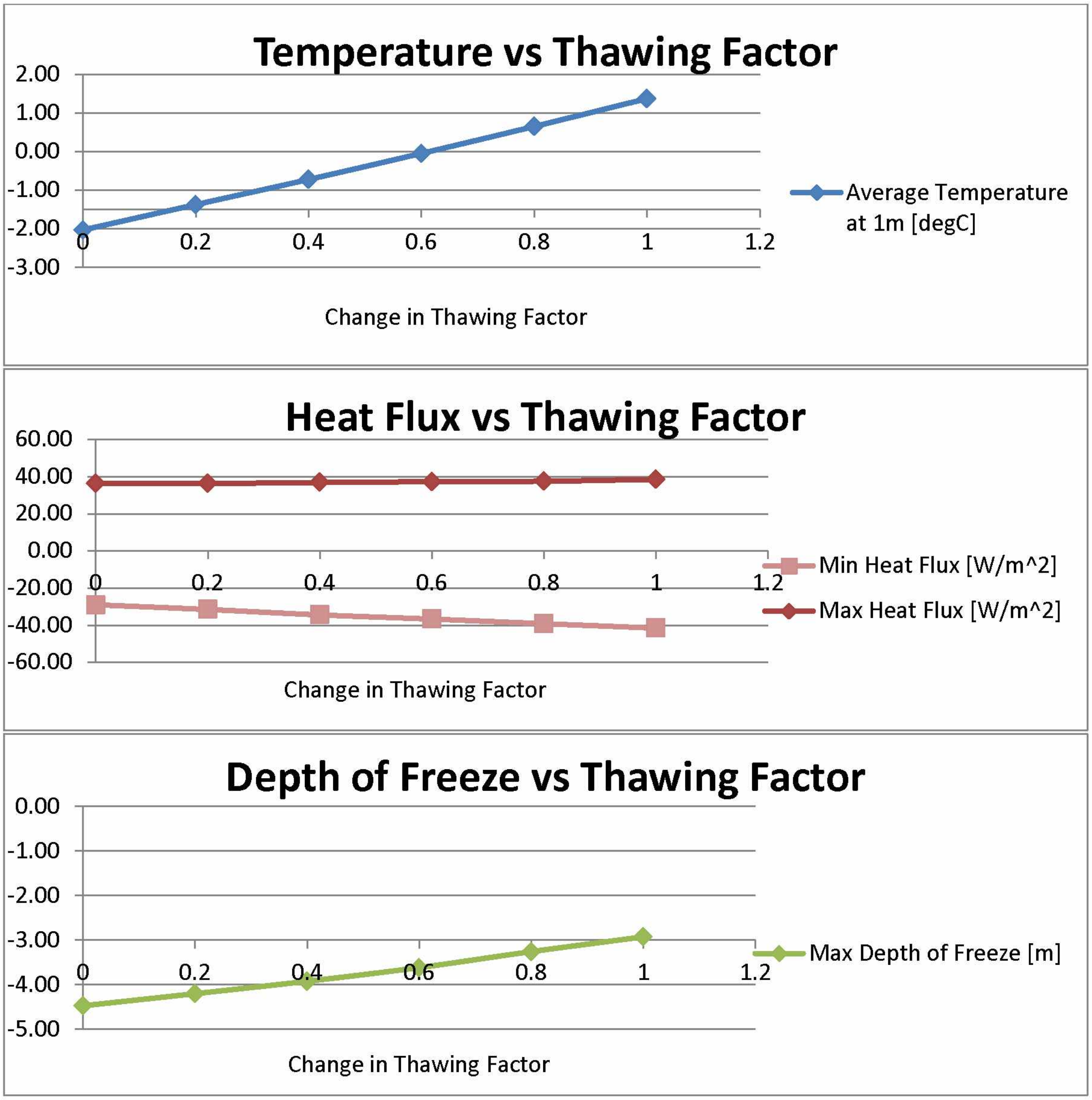
Figures 12 a-c: Density Change vs Heat Metrics in Silty Soils



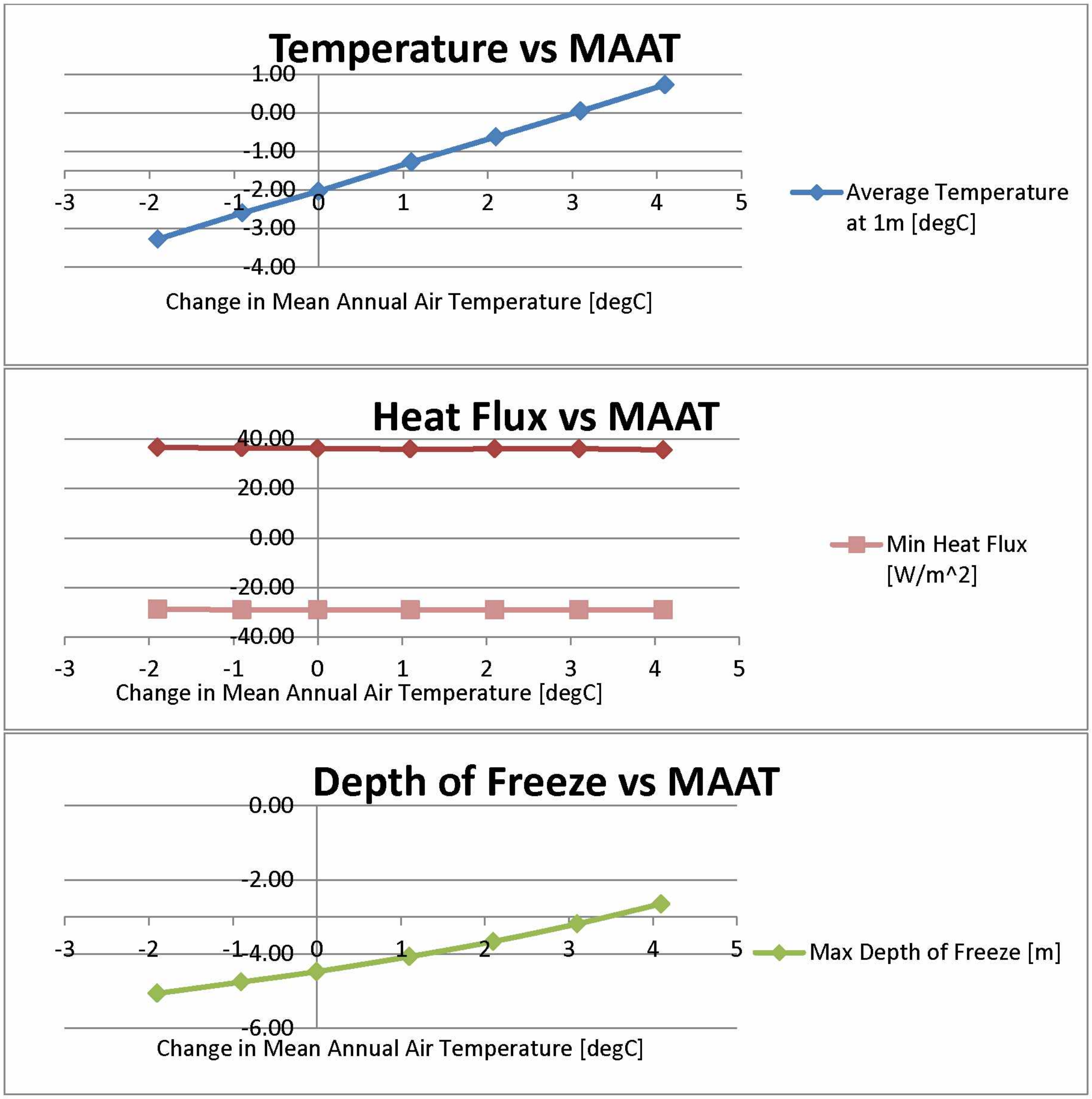
<u>Figures 13 a-c: Moisture Content vs Heat Metrics in Silty Soils</u>



Figures 14a-c: Freezing Factor vs Heat Metrics in Silty Soils



Figures 15 a-c: Thawing Factor vs Heat Metrics in Silty Soils



Figures 16 a-c: Mean Annual Air Temperature vs Heat Metrics in Silty Soils

2.10 Observations

From these graphs a few discernable observations can be made.

Density and Water Content: As expected, increase in these variables each increases the maximum and minimum heat flux into the system. This should allow for more heat to enter the soil and allow for a more efficient heat pump.

Atmospheric Factors: These had a lot less dramatic effect on peak heat flux though there effect on depth of freeze or whether or not permafrost was naturally developing. Looking at only this data set it is hard to discern which “N” factor, freezing or thawing, is more important for a GSHP. For that soil temperatures will be looked at in the next data set.

CHAPTER 3: INTEGRATION OF GSHP

3.1 Description

As a secondary portion to this project, the model from the first section was further complicated by adding a heat flux element based off the physical dimensions of the physical loop field. Several simplifications were made to reduce model complexity and reduce overall calculation times and allow for ease of manipulation.

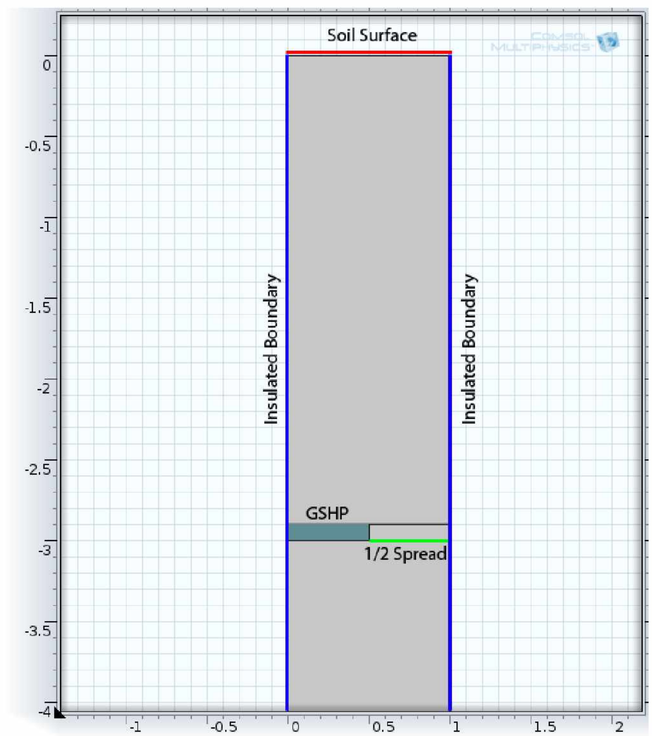


Figure 17: Basic GSHP Model

This model represents a segment in the center of the loop field. This provides several benefits. First, this location provides the lowest temperatures and shows where the worst case scenario for ground temperatures will be. Second, the geometry of the location allows for several simplifications. The central location prevents lateral heat flow and allows the simulation to look at a much smaller chunk of soil. This vastly decreases the amount of calculations and maximizes simplicity for an accurate thermal model.

3.2 Heat Load

Similar to part one of this report, this model was utilized to check the influence of various input parameters and how they affected the GSHP performance. Several aspects were tested including: building heat load, soil moisture content, placement of loop component on the long-term temperatures in the field and similar soil and environmental properties were tested in part one of this report.

3.5 Parameters:

In addition to the properties tested in Chapter 2, two additional properties were tested which related to the introduction of the GSHP.

<u>Peak Heat:</u> This metric is the maximum demand from the GSHP. For the model, the peak heat is produced on the coldest days. These values used are based off of the original building heating load calculations done by the Jack Herbert for CCHRC main Fairbanks facility. While the value tested is somewhat arbitrary, it provides a good base line for viability of a medium demand GSHP.

<u>½ Spread:</u> This parameter is one half the distance between loops. Having loops too close to each other will reduce the amount of overall heat each can absorb. Having them too far apart will unreasonably increase the overall foot print of the field. This parametric will slowly be increased to measure its effect on the long term viability of the loop field.

3.4 Metrics

Minimum and maximum heat flux and depth of freeze were measured in the same way as chapter 2 of this report. Several modifications were made to measure the effects of different parameters.

Temperature was measured on the upper and lower border of the GSHP. The minimum of these temperatures was recorded at the end of the 30 year study period. The average of the last 5 years of the study period was also recorded.

One more metric was determining when the boundary of the GSHP dropped below -5˚C. This value was chosen from criteria given by CCHRC. CCHRC's heat pump is more efficient than their conventional heating system until the soil temperatures reach below -7˚C. The -5˚C criteria will give a good metric in determining how long the loop field may remain economical over conventional heating systems.

3.5 Results

As in the previous chapter, numerous simulation runs were taken for both sandy and silty based soils. The results from these runs are shown on the following pages:

Table 3: Raw Simulation Data for Sandy Soils with GSHP

Soil Properties					Environmental Factors						Simulation Results					
Soil Type	Independent Paramet		Thermal Diffusivity		Surface 'N' Factors			GSHP					Heat Flux [W/m²]			
Sand	ρ [kg/m³]	W	Frozen[m²/s]	Unfrozen[m²/s]	Freezing	Thawing	MAAT [°C]	Peak Heat [W]	½ Spread [m]	DELTA	3m Avg [°C]	3m Min [°C]	Max	Min	Depth of Freeze [m]	At -5degC [Yr]
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	23.3	0.5	11.641	-12.84	-25.73	42.74	-42.02	-18.63	1.2
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	21.0	0.5	9.316	-11.79	-24.09	42.54	-41.54	-17.86	1.2
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	18.6	0.5	6.987	-10.77	-22.10	42.70	-40.36	-17.23	1.2
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	16.3	0.5	4.658	-9.7661	-20.50	42.96	-40.05	-16.61	1.2
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	14.0	0.5	2.329	-8.72	-18.64	42.73	-39.68	-15.75	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.5	0	-7.74	-17.07	43.10	-38.69	-15.17	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	9.3	0.5	-2.329	-6.74	-15.27	42.64	-37.90	-14.43	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	7.0	0.5	-4.658	-5.75	-13.46	42.80	-36.73	-13.62	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	4.7	0.5	-6.987	-4.76	-11.50	42.83	-36.24	-12.63	3.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	2.3	0.5	-9.316	-3.80	-9.44	42.85	-35.23	-11.70	4.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.1	-0.4	-11.15	-22.79	42.69	-40.41	-17.96	0.2
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.2	-0.3	-9.85	-20.62	42.58	-40.11	-16.73	1.2
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.5	0	-7.74	-17.07	43.10	-38.69	-15.17	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	1	0.5	-6.21	-14.31	42.80	-36.91	-13.76	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	1.6	1.1	-5.42	-12.89	42.77	-36.26	-12.89	3.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	2.2	1.7	-5.27	-12.33	42.98	-37.56	-12.80	3.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	2.8	2.3	-4.77	-11.44	42.71	-35.85	-11.73	4.0
		is the variable being parameterized in the simulation run.														

Soil Properties					Environmental Factors						Simulation Results					
Soil Type	Independent Paramet		Thermal Diffusivity		Surface 'N' Factors			GSHP					Heat Flux [W/m²]			
Sand	ρ [kg/m³]	W	Frozen[m²/s]	Unfrozen[m²/s]	Freezing	Thawing	MAAT [°C]	Peak Heat [W]	½ Spread [m]	DELTA	3m Avg [°C]	3m Min [°C]	Max	Min	Depth of Freeze [m]	At -5degC [Yr]
	1800	30.00%	2.49E-06	4.50E-03	1	1	-2.1	11.6	0.5	400	-6.23	-15.58	66.82	-52.48	-20.00	1.05
	1600	30.00%	1.85E-06	3.37E-03	1	1	-2.1	11.6	0.5	200	-6.76	-16.03	53.62	-45.31	-17.38	1.09
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.5	0	-7.74	-17.07	43.10	-38.69	-15.17	2.1
	1200	30.00%	1.07E-06	1.90E-03	1	1	-2.1	11.6	0.5	-200	-9.37	-19.07	34.39	-32.47	-13.62	2.05
	1400	70.00%	1.99E-03	3.54E-04	1	1	-2.1	11.6	0.5	40.00%	-6.07	-14.25	97.468	-60.241	-13.192	3.07
	1400	60.00%	1.89E-03	3.87E-04	1	1	-2.1	11.6	0.5	30.00%	-6.52	-15.13	82.945	-54.83	-14.9	2.05
	1400	50.00%	1.76E-03	4.28E-04	1	1	-2.1	11.6	0.5	20.00%	-6.63	-15.38	69.78	-49.803	-14.31	2.05
	1400	40.00%	1.60E-03	4.79E-04	1	1	-2.1	11.6	0.5	10.00%	-7.02	-16.62	56.17	-44.75	-14.498	2.1
	1400	30.00%	1.39E-03	5.42E-04	1	1	-2.1	11.6	0.5	0.00%	-7.74	-17.07	43.10	-38.69	-15.17	2.1
	1400	20.00%	1.12E-03	6.22E-04	1	1	-2.1	11.6	0.5	-10.00%	-9.08	-18.96	29.412	-31.33	-15.72	2.1
	1400	10.00%	7.25E-04	6.99E-04	1	1	-2.1	11.6	0.5	-20.00%	-13.47	-25.20	20.01	-22.78	-19.121	1.07
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.5	0	-7.74	-17.07	43.10	-38.69	-15.17	2.1
	1400	30.00%	1.39E-06	2.53E-03	0.9	1	-2.1	11.6	0.5	-0.1	-7.05	-15.79	40.52	-37.89	-14.47	2.1
	1400	30.00%	1.39E-06	2.53E-03	0.8	1	-2.1	11.6	0.5	-0.2	-6.40	-14.33	38.86	-37.35	-13.91	2.1
	1400	30.00%	1.39E-06	2.53E-03	0.7	1	-2.1	11.6	0.5	-0.3	-5.80	-13.09	35.52	-36.46	-13.55	2.2
	1400	30.00%	1.39E-06	2.53E-03	0.6	1	-2.1	11.6	0.5	-0.4	-5.05	-11.36	32.79	-37.39	-12.39	4.14
	1400	30.00%	1.39E-06	2.53E-03	0.5	1	-2.1	11.6	0.5	-0.5	-4.55	-10.05	29.97	-35.68	-12.39	4.2
	1400	30.00%	1.39E-06	2.53E-03	1	2	-2.1	11.6	0.5	1	-5.18	-13.61	44.14	-51.67	-13.12	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1.8	-2.1	11.6	0.5	0.8	-5.68	-14.33	43.80	-49.29	-13.57	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1.6	-2.1	11.6	0.5	0.6	-6.18	-15.13	43.21	-46.43	-13.96	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1.4	-2.1	11.6	0.5	0.4	-6.70	-15.80	43.10	-43.23	-14.39	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1.2	-2.1	11.6	0.5	0.2	-7.22	-16.64	43.08	-40.95	-14.79	2.1
	1400	30.00%	1.39E-06	2.53E-03	1	1	-2.1	11.6	0.5	0	-7.74	-17.07	43.10	-38.69	-15.17	2.1
		is the variable being parameterized in the simulation run.														

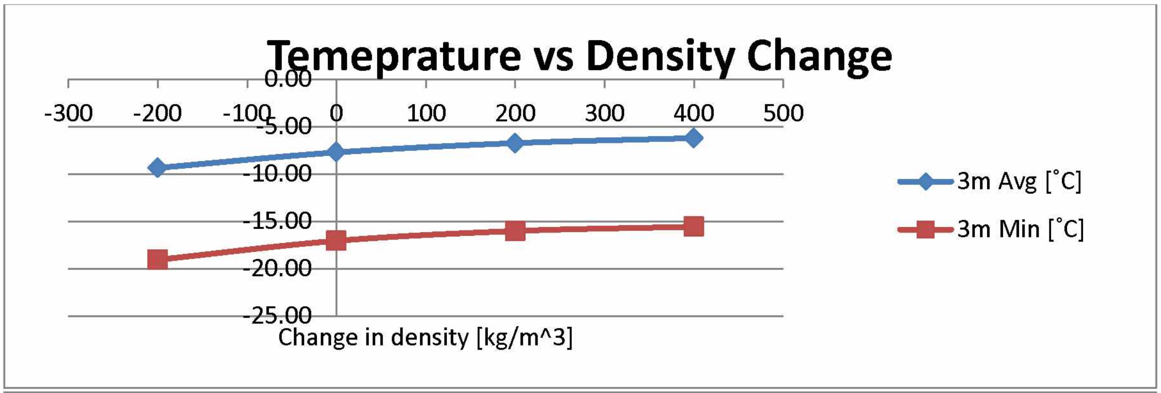
Soil Properties					Environmental Factors						Simulation Results					
Soil Type	Independent Parameters		Thermal Diffusivity		Surface 'N' Factors			GSHP					Heat Flux [W/m^2]			
Silt / Clay	ρ [kg/m^3]	W	Frozen[m^2/s]	Unfrozen[m^2/s]	Freezing	Thawing	MAAT [˚C]	Peak Heat [W]	½ Spread [m]	DELTA	3m Avg [˚C]	3m Min [˚C]	Max	Min	Depth of Freeze [m]	At -5degC [Yr]
	1800	30.00%	1.24E-06	3.41E-03	1	1	-2.1	11.6	0.5	400	-6.63	-14.94	48.25	-50.39	-15.43	2.07
	1600	30.00%	1.06E-06	2.56E-03	1	1	-2.1	11.6	0.5	200	-7.67	-16.15	41.42	-39.76	-14.46	2.07
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.5	0	-9.00	-17.87	35.58	-33.73	-13.74	2.07
	1200	30.00%	8.48E-07	1.44E-03	1	1	-2.1	11.6	0.5	-200	-10.67	-20.14	31.32	-29.42	-13.21	2.07
	1400	70.00%	1.36E-03	2.99E-04	1	1	-2.1	11.6	0.5	40.00%	-6.38	-14.18	80.98	-55.91	-12.07	3.07
	1400	60.00%	1.28E-03	3.22E-04	1	1	-2.1	11.6	0.5	30.00%	-6.68	-14.65	69.78	-50.45	-12.28	3.07
	1400	50.00%	1.19E-03	3.48E-04	1	1	-2.1	11.6	0.5	20.00%	-7.12	-15.29	58.43	-45.93	-12.57	2.07
	1400	40.00%	1.08E-03	3.78E-04	1	1	-2.1	11.6	0.5	10.00%	-7.81	-16.30	47.18	-40.20	-13.01	2.10
	1400	30.00%	9.34E-04	4.11E-04	1	1	-2.1	11.6	0.5	0.00%	-9.00	-17.87	35.58	-33.73	-13.74	2.07
	1400	20.00%	7.45E-04	4.39E-04	1	1	-2.1	11.6	0.5	-10.00%	-11.45	-21.13	24.62	-27.18	-15.11	1.20
	1400	10.00%	4.83E-04	4.17E-04	1	1	-2.1	11.6	0.5	-20.00%	-18.45	-30.15	13.62	-19.07	-18.37	0.94
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.5	0	-9.00	-17.87	35.58	-33.73	-13.74	2.07
	1400	30.00%	9.34E-07	1.92E-03	0.9	1	-2.1	11.6	0.5	-0.1	-8.36	-16.63	33.98	-33.38	-13.37	2.10
	1400	30.00%	9.34E-07	1.92E-03	0.8	1	-2.1	11.6	0.5	-0.2	-7.73	-15.44	31.92	-32.94	-12.96	2.14
	1400	30.00%	9.34E-07	1.92E-03	0.7	1	-2.1	11.6	0.5	-0.3	-7.10	-14.23	29.80	-32.19	-12.57	2.25
	1400	30.00%	9.34E-07	1.92E-03	0.6	1	-2.1	11.6	0.5	-0.4	-6.48	-12.86	27.54	-31.64	-12.18	3.15
	1400	30.00%	9.34E-07	1.92E-03	0.5	1	-2.1	11.6	0.5	-0.5	-5.87	-11.57	24.95	-31.41	-11.41	4.14
	1400	30.00%	9.34E-07	1.92E-03	1	2	-2.1	11.6	0.5	1	-6.20	-14.24	36.99	-45.94	-12.01	3.14
	1400	30.00%	9.34E-07	1.92E-03	1	1.8	-2.1	11.6	0.5	0.8	-6.76	-14.99	36.62	-43.71	-12.38	2.19
	1400	30.00%	9.34E-07	1.92E-03	1	1.6	-2.1	11.6	0.5	0.6	-7.31	-15.77	36.26	-41.77	-12.75	2.15
	1400	30.00%	9.34E-07	1.92E-03	1	1.4	-2.1	11.6	0.5	0.4	-7.87	-16.54	36.18	-39.24	-13.09	2.12
	1400	30.00%	9.34E-07	1.92E-03	1	1.2	-2.1	11.6	0.5	0.2	-8.42	-17.03	36.06	-37.25	-13.42	2.09
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.5	0	-9.00	-17.87	35.58	-33.73	-13.74	2.07

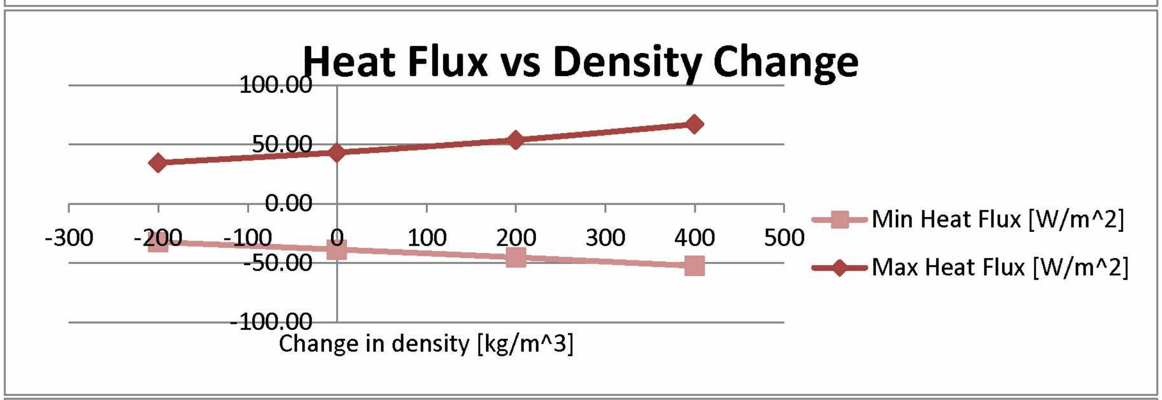
is the variable being parameterized in the simulation run.

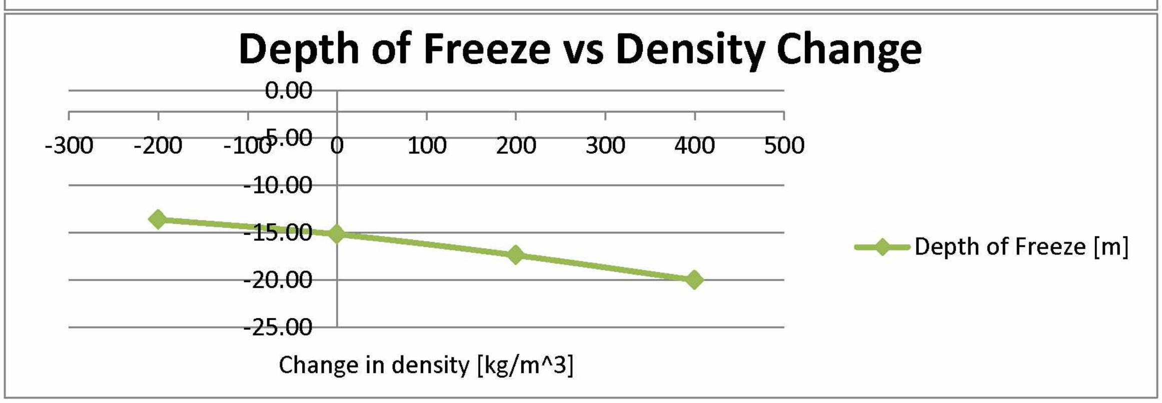
Soil Properties					Environmental Factors						Simulation Results					
Soil Type	Independent Parameters		Thermal Diffusivity		Surface 'N' Factors			GSHP					Heat Flux [W/m^2]			
Silt / Clay	ρ [kg/m^3]	W	Frozen[m^2/s]	Unfrozen[m^2/s]	Freezing	Thawing	MAAT [˚C]	Peak Heat [W]	½ Spread [m]	DELTA	3m Avg [˚C]	3m Min [˚C]	Max	Min	Depth of Freeze [m]	At -5degC [Yr]
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	23.3	0.5	11.641	-16.08	-29.32	35.87	-38.01	-17.28	1.05
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	21.0	0.5	9.316	-14.65	-26.95	35.66	-36.98	-16.64	1.08
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	18.6	0.5	6.987	-13.23	-24.64	35.87	-36.35	-16.00	1.13
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	16.3	0.5	4.658	-11.81	-22.33	35.81	-35.29	-15.25	1.15
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	14.0	0.5	2.329	-10.40	-20.10	35.84	-34.61	-14.55	2.05
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.5	0	-9.00	-17.87	35.58	-33.73	-13.74	2.07
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	9.3	0.5	-2.329	-7.61	-15.63	35.93	-33.61	-12.93	2.12
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	7.0	0.5	-4.658	-6.23	-13.27	35.83	-31.82	-12.00	3.11
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	4.7	0.5	-6.987	-4.88	-10.87	35.87	-31.36	-10.99	4.14
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	2.3	0.5	-9.316	-3.57	-8.15	35.90	-30.98	-9.83	7.15
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.1	-0.4	-13.52	-25.25	35.77	-36.70	-15.83	0.90
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.2	-0.3	-11.95	-22.52	35.72	-35.70	-15.52	0.90
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	0.5	0	-9.00	-17.87	35.58	-33.73	-13.74	2.1
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	1	0.5	-6.89	-14.43	35.97	-32.64	-12.26	2.10
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	1.6	1.1	-5.93	-12.68	36.07	-31.57	-11.64	2.10
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	2.2	1.7	-5.32	-11.55	35.86	-31.43	-10.77	3.10
	1400	30.00%	9.34E-07	1.92E-03	1	1	-2.1	11.6	2.8	2.3	-5.09	-11.24	36.09	-31.49	-9.93	3.10

Table 4: Raw Simulation Data for Silty Soils with GSHP

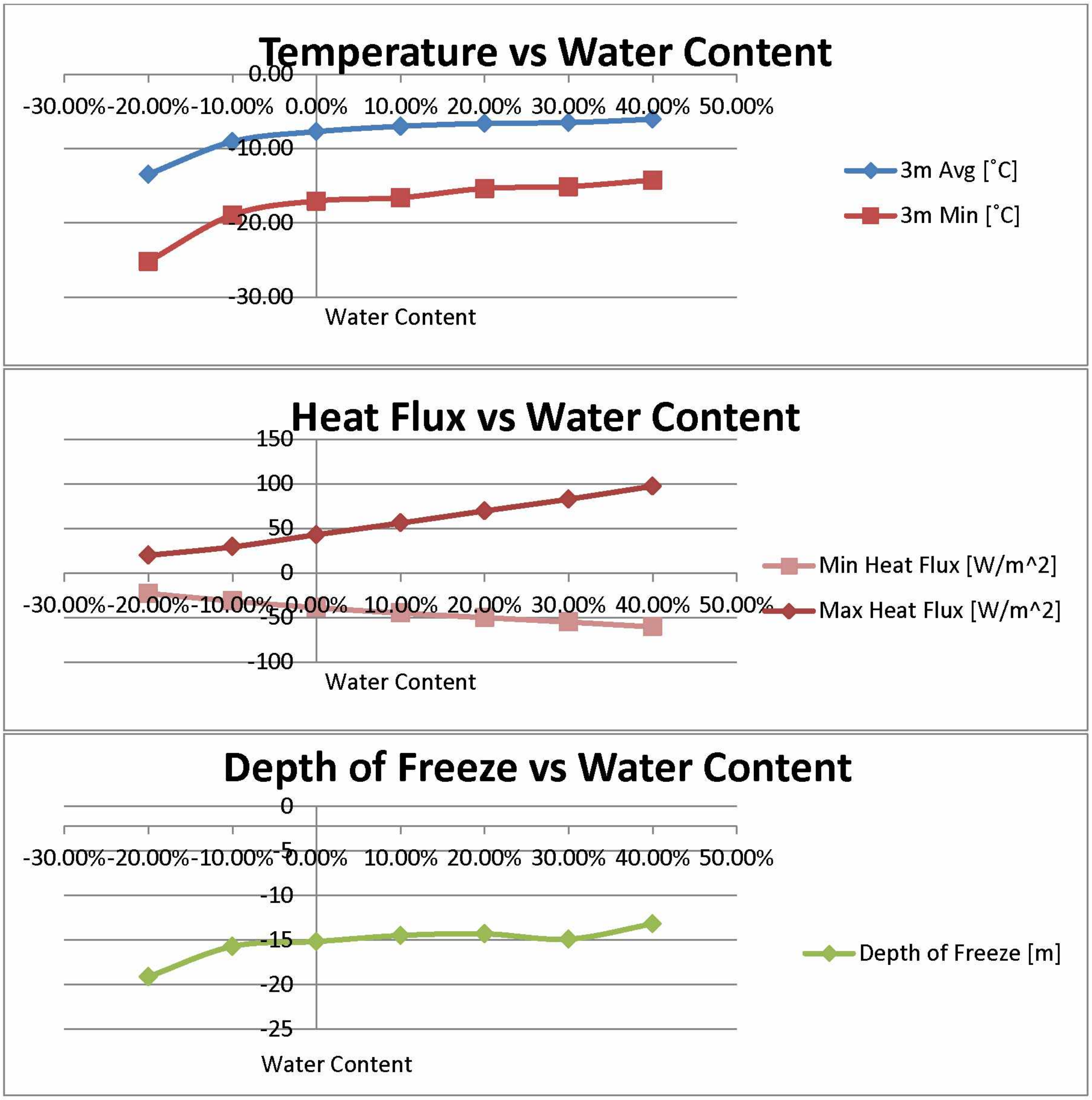
The following are the graphs for sandy soils with a GSHP:



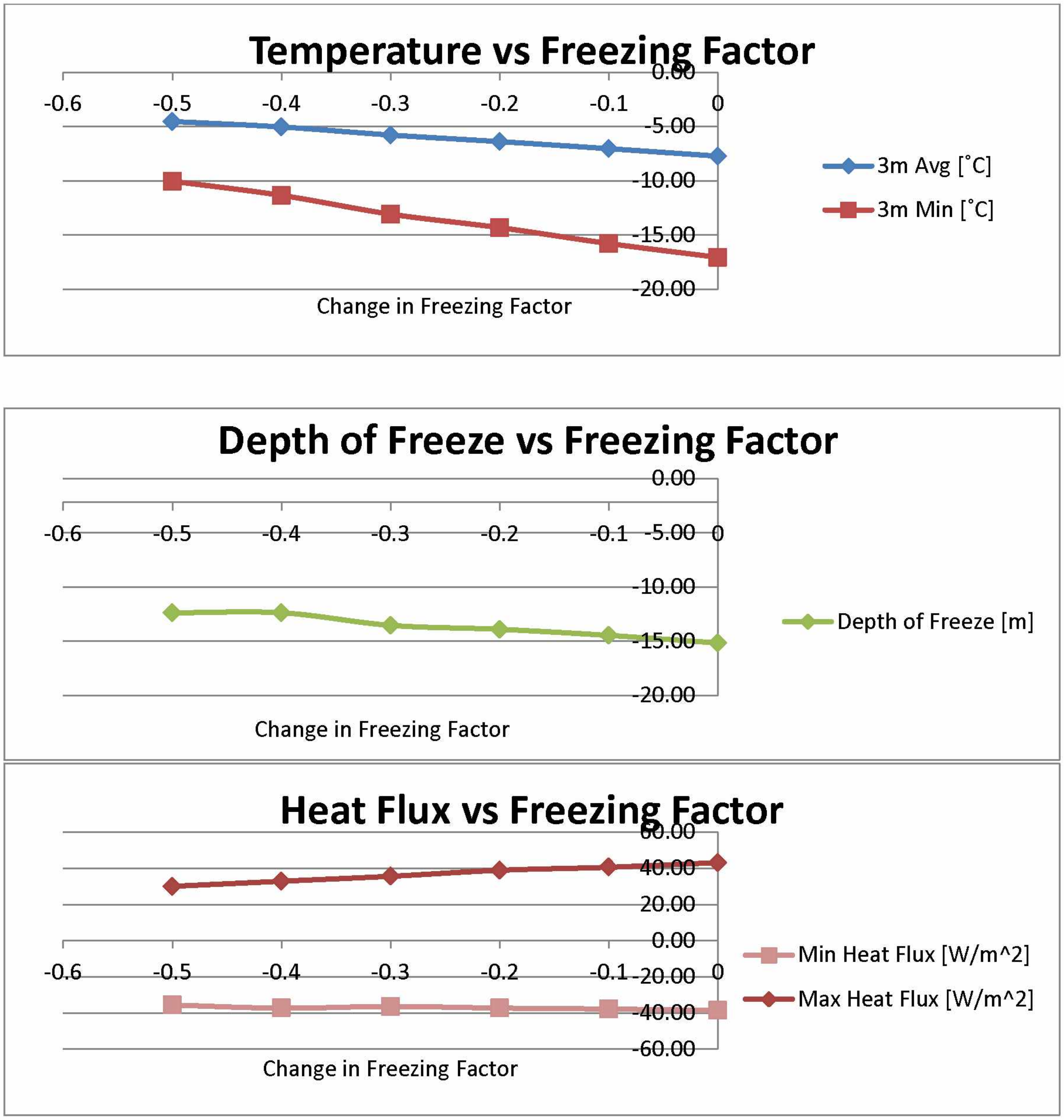




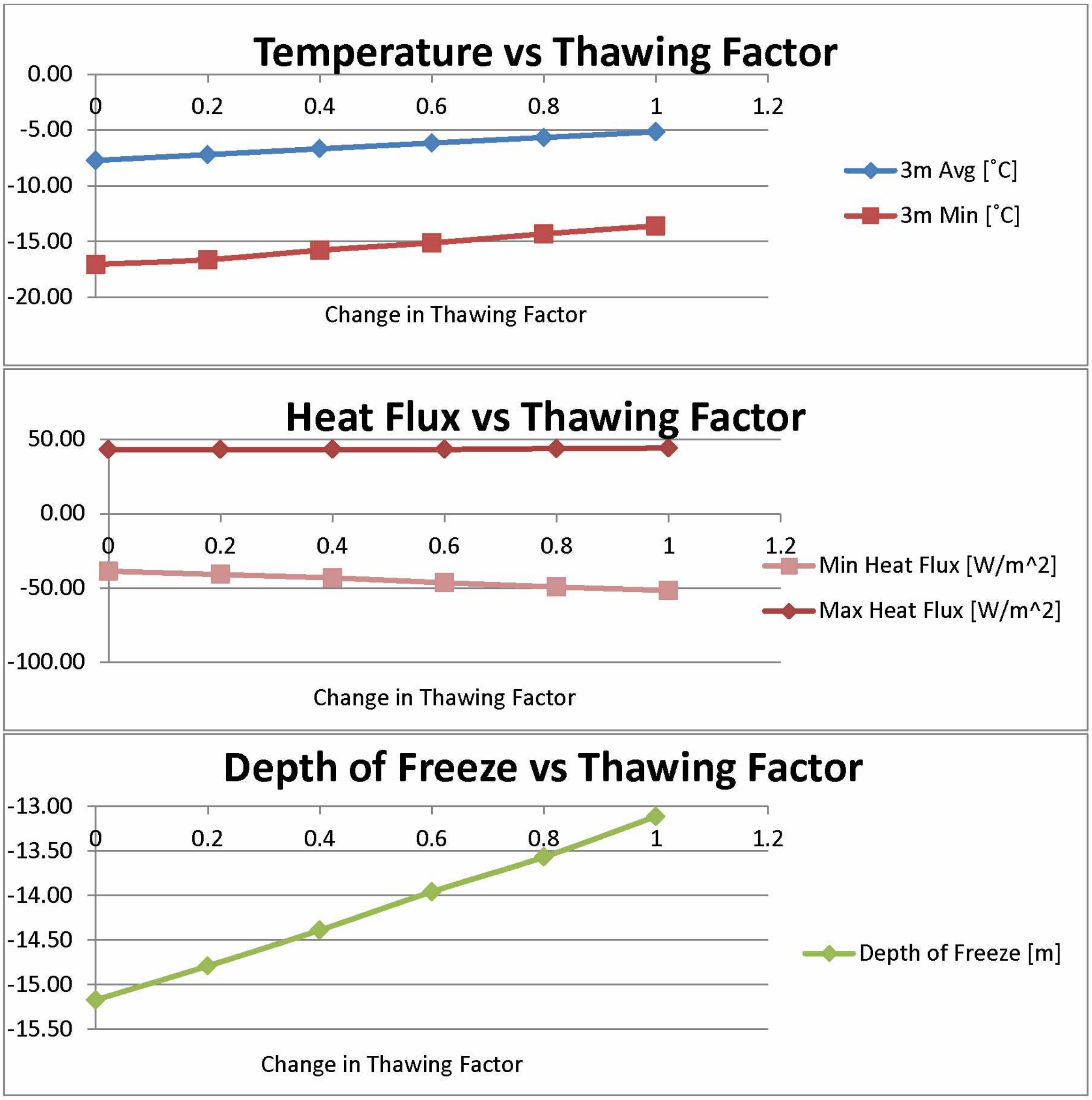
Figures 18a-c: Density Change vs Heat Metrics in Sandy Soils with GSHP



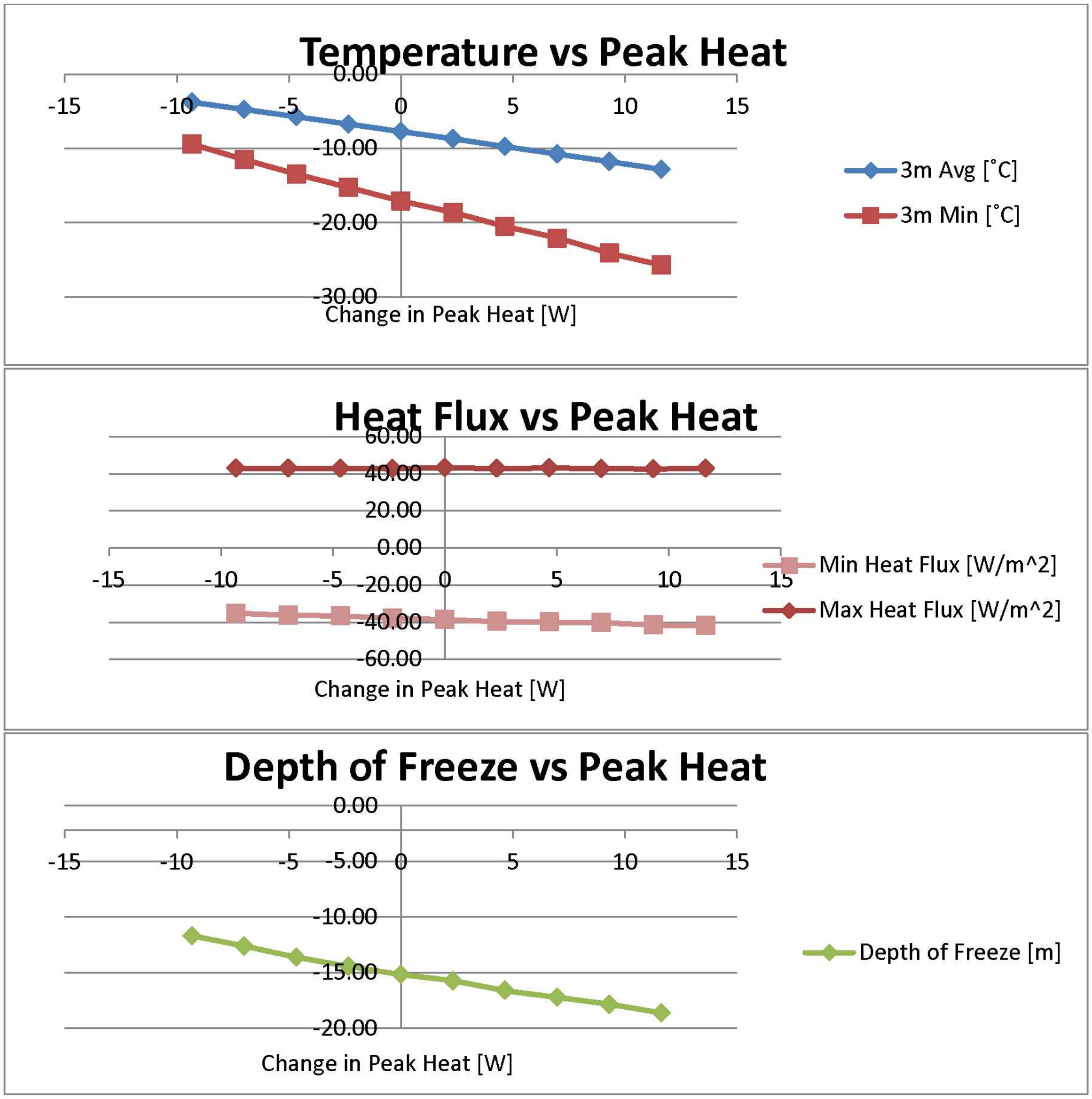
Figures 19 a-c: Water Content vs Heat Metrics in Sandy Soils with GSHP



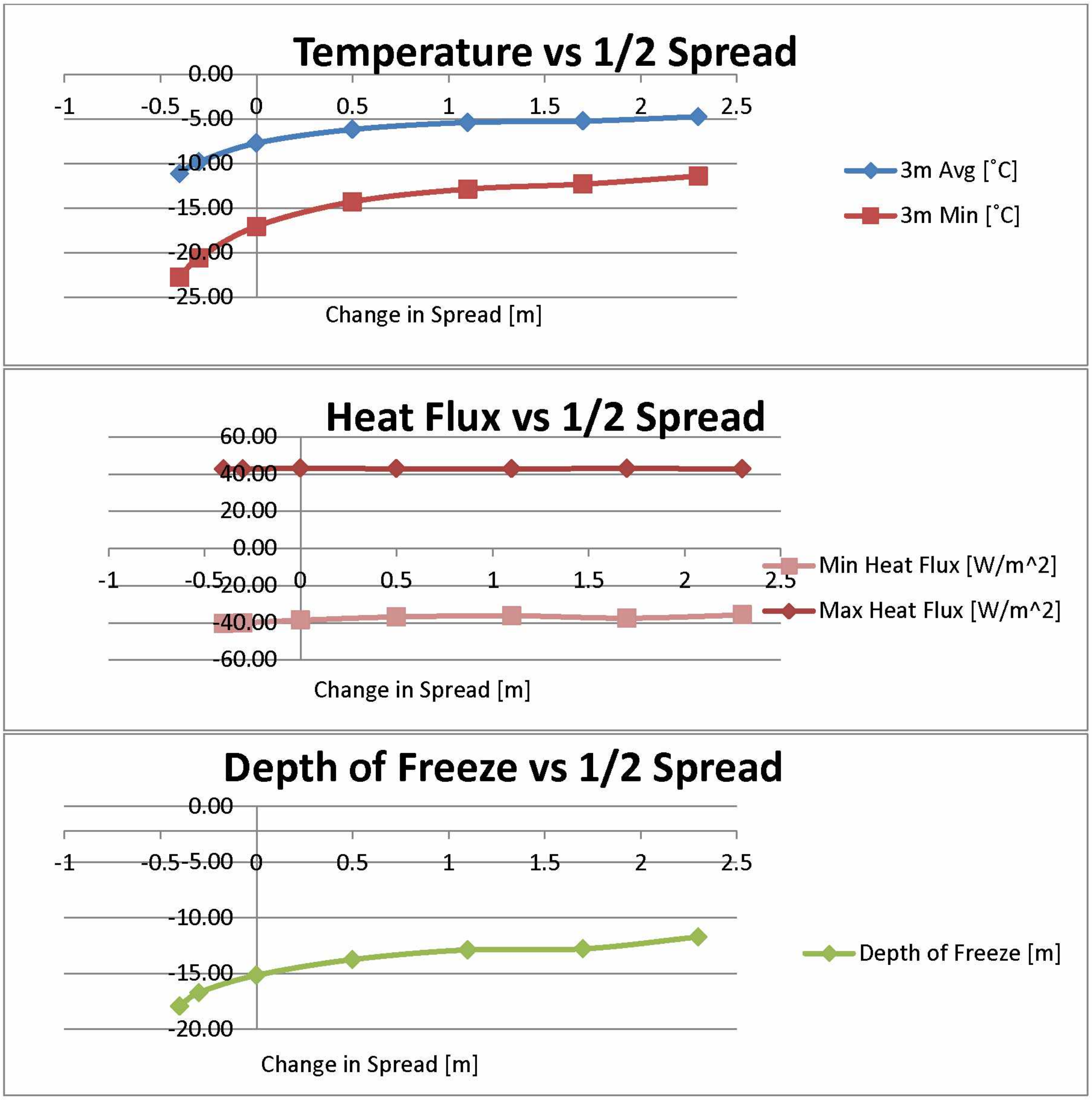
Figures 20 a-c: Freezing Factor vs Heat Metrics in Sandy Soils with GSHP



Figures 21 a-c: Thawing Factor vs Heat Metrics in Sandy Soils with GSHP

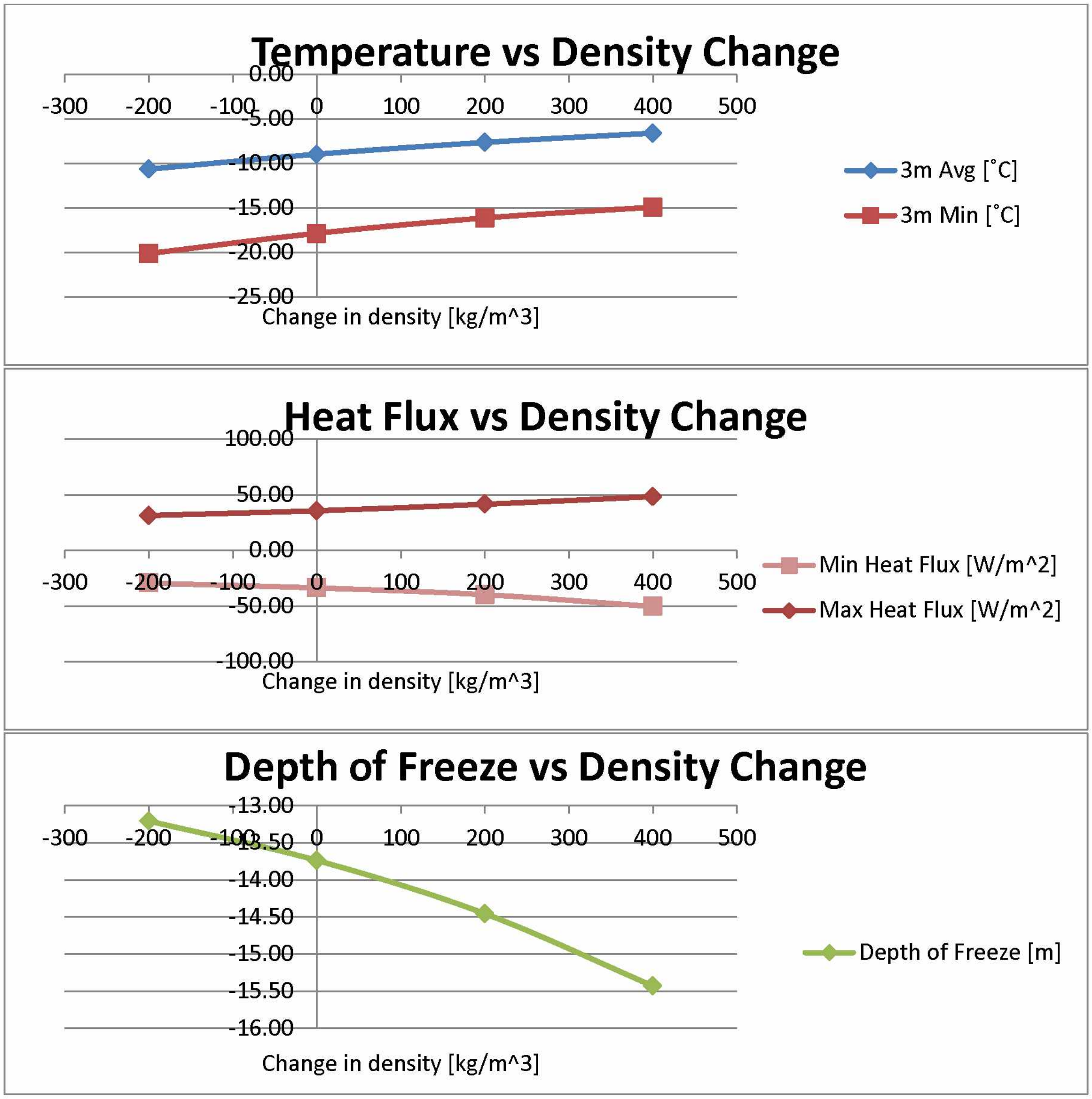


Figures 22 a-c: Peak Heat vs Heat Metrics in Sandy Soils with GSHP

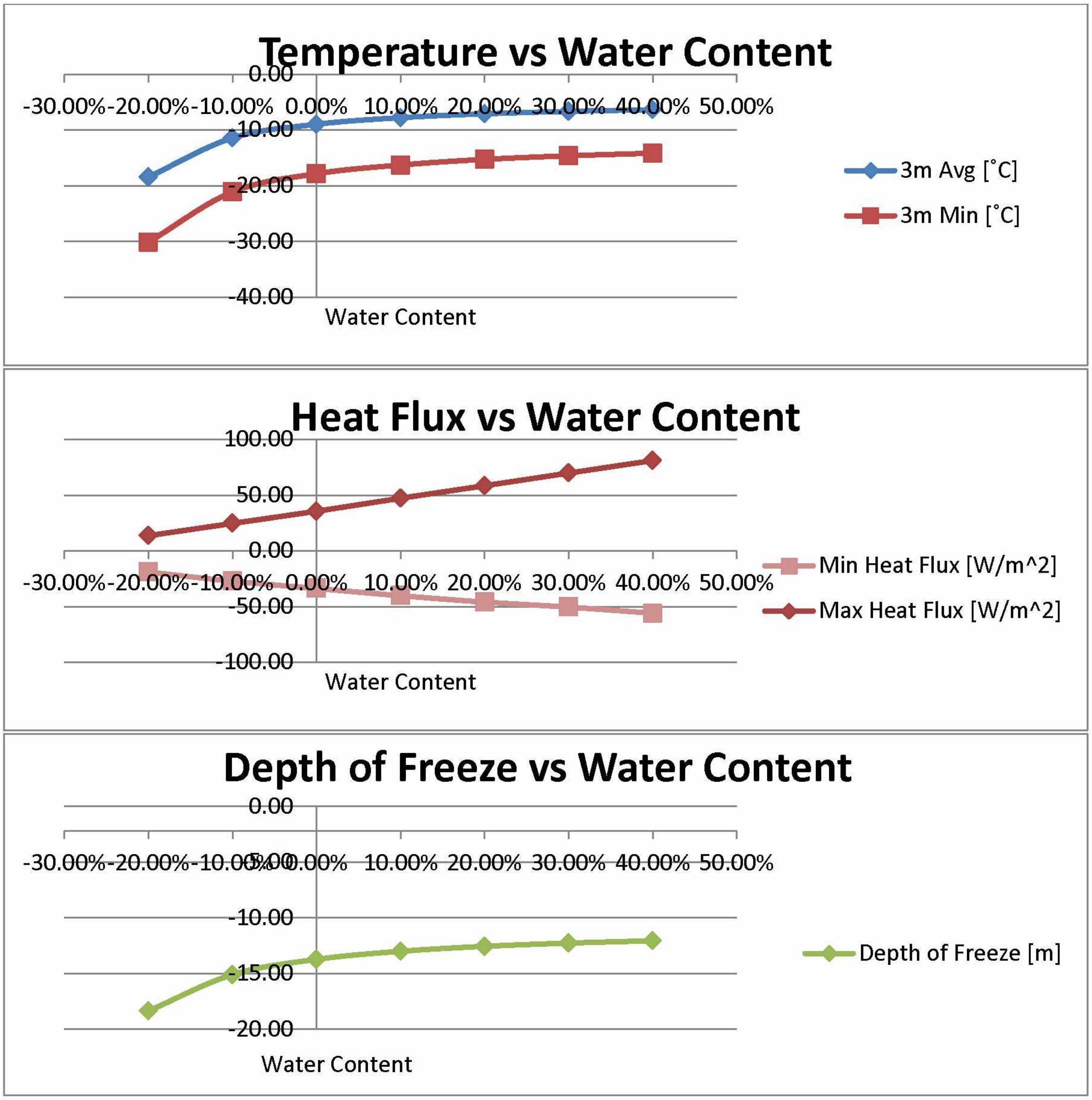


Figures 23 a-c: Spread vs Heat Metrics in Sandy Soils with GSHP

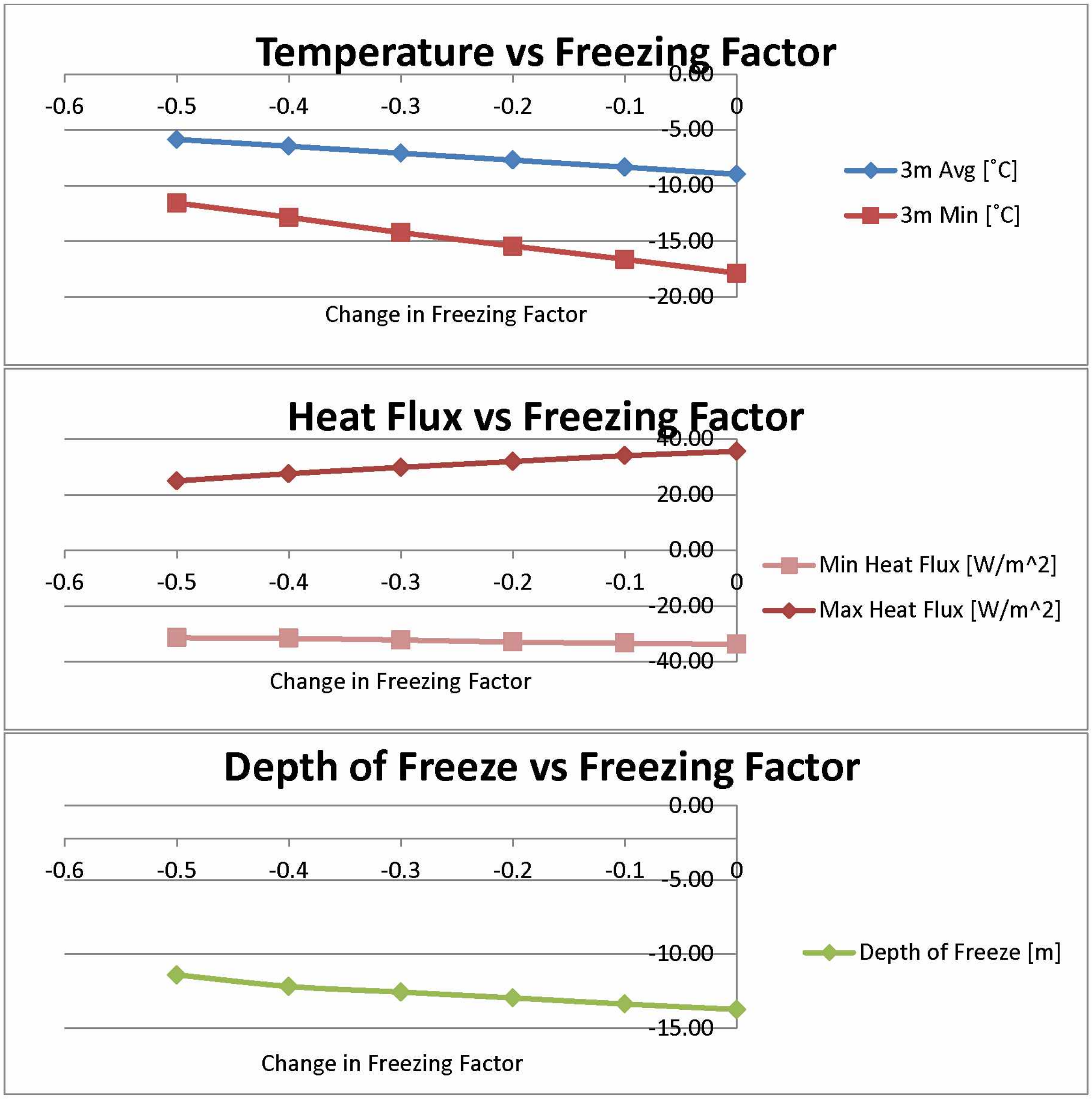
Additionally for silty soils:



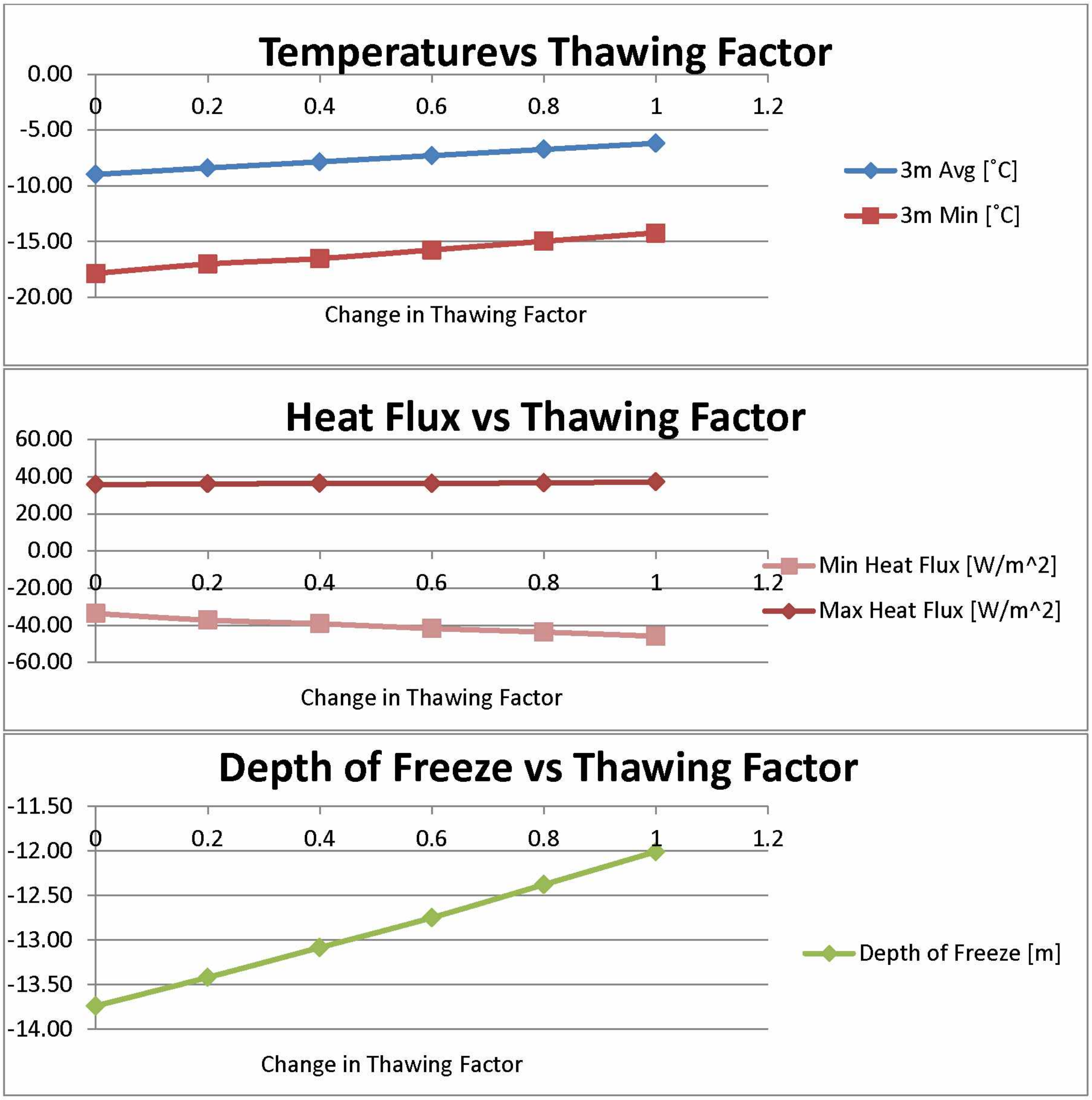
Figures 24 a-c: Density Change vs Heat Metrics in Silty Soils with GSHP



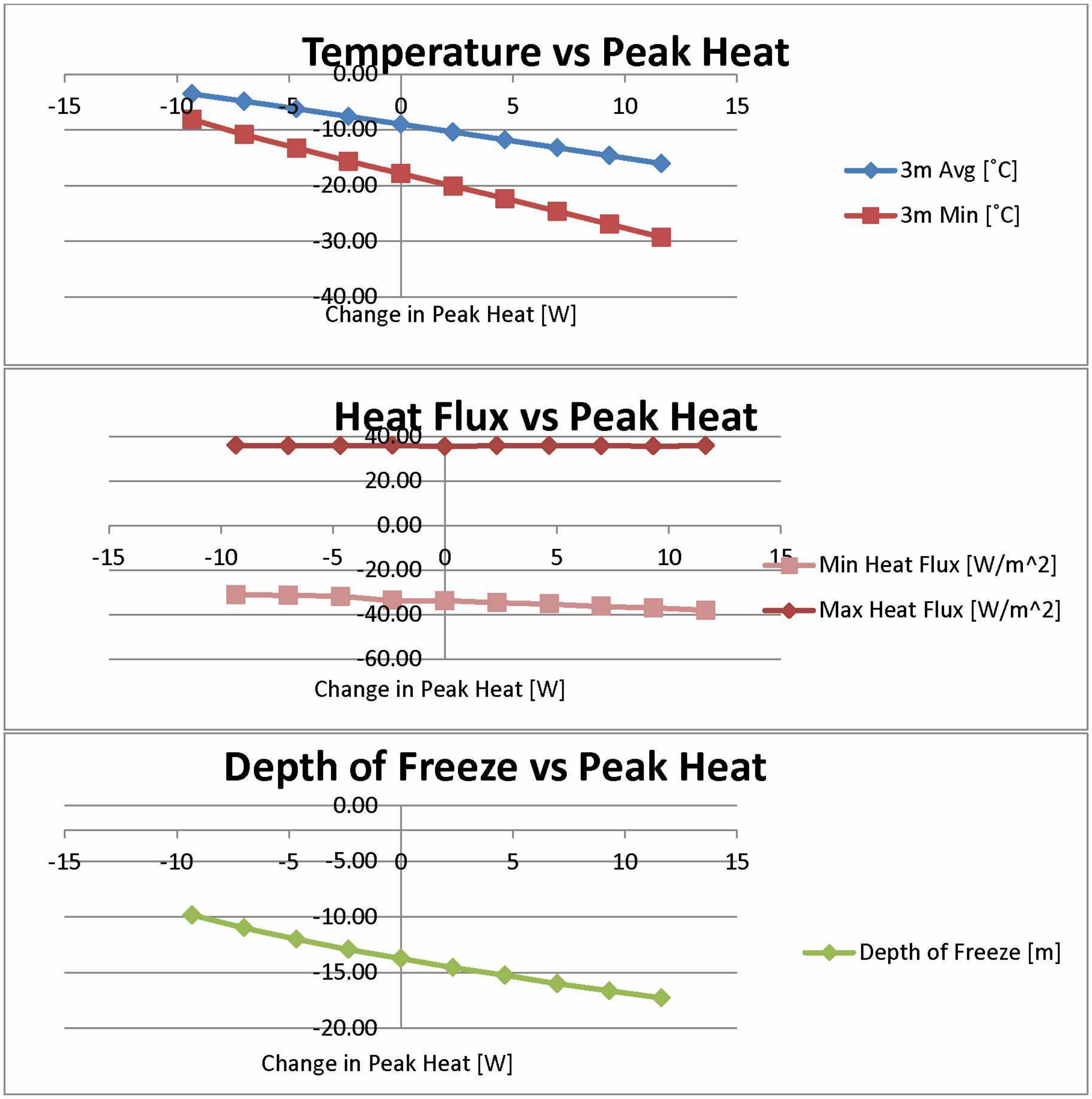
Figures 25 a-c: Water Content vs Heat Metrics in Silty Soils with GSHP



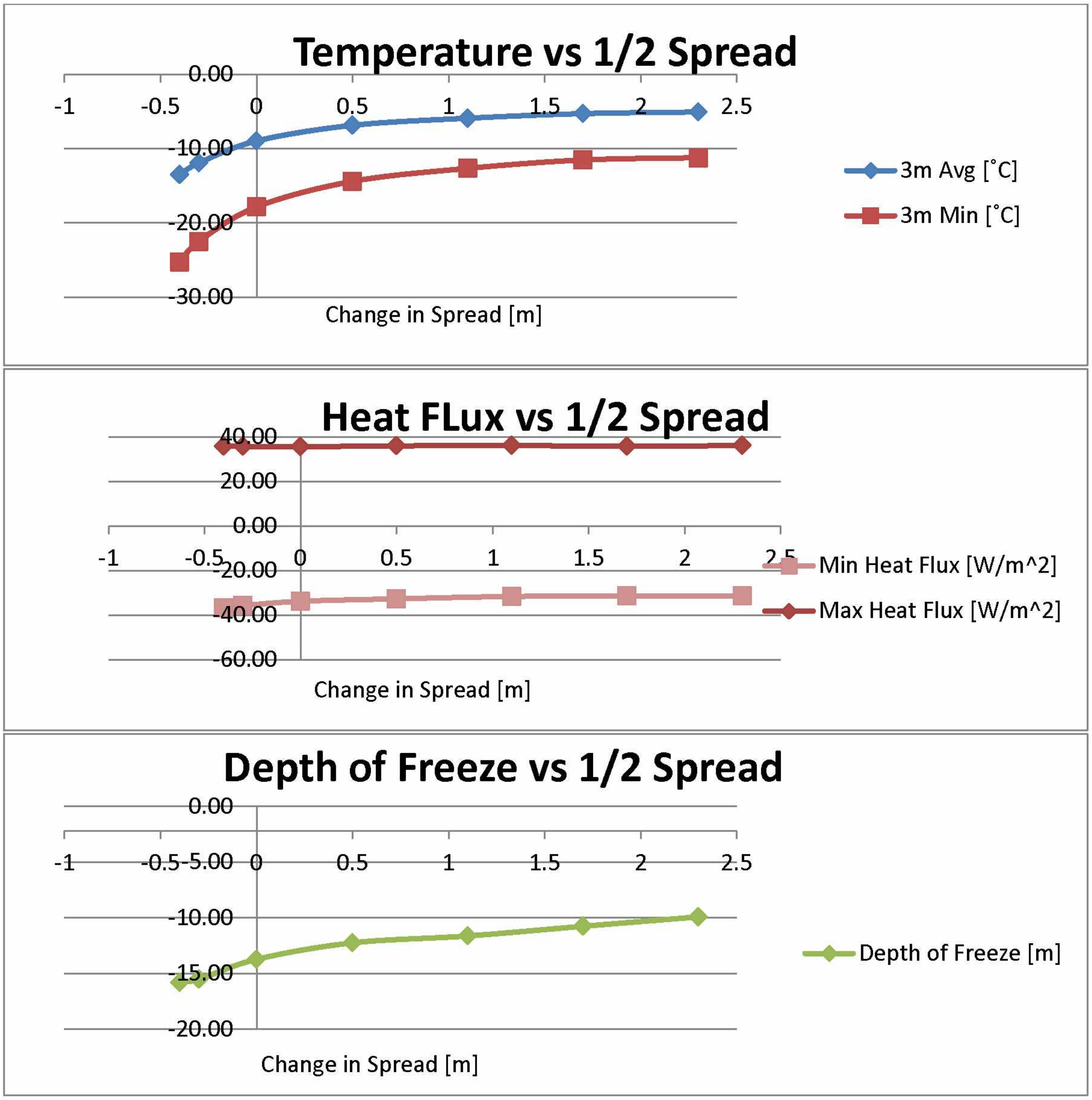
Figures 26 a-c: Freezing Factor vs Heat Metrics in Silty Soils with GSHP



Figures 27 a-c: Thawing Factor vs Heat Metrics in Silty Soils with GSHP



Figures 28 a-c: Peak Heat vs Heat Metrics in Silty Soils with GSHP



Figures 29 a-c: ½ Loop Spread vs Heat Metrics in Silty Soils with GSHP

3.6 Observations:

As noted in the previous chapter, water content and density play a large role in the long term viability of a loop field. While density seems to increase depth of freeze over time it also led to more sustainable temperatures for both soil types long term. High moisture contents allowed the heat of fusion to absorb large amounts of heat. This also contributed to viability long term.

The simulations also suggest that silty soils perform slightly better than courser grained soils, although the difference appears to be marginal on the most part. Changing the physical characteristics of the loop field also greatly changed the temperature profile. The relation between loop separation and loop temperatures appears to decay exponentially. Spreading the loop out say 2 meters apart compared to one meter would have a large impact on sustainability.

While looking at how the different “N” factors affect the loop, it appears that the freezing factor is more important. What that means is that it is more important to insulate the soil surface, wither naturally with snow cover of with some kind of artificial insulation than to promote heat penetration with a dark highly conductive surface such as asphalt. This would be interesting to test in real life as an experiment beyond the scope of this project.

CHAPTER 4: CCHRC DATA INTEGRATION

4.1 Introduction

As a final experiment some of the temperature data collected from CCHRC’s GSHP and added to the existing 2-D GSHP model from Chapter 3. This data along with a core sampling which contained soil type and moisture content collected from the site were combined to make a predictive model of the GSHP’s long term performance. This model has the same basic parameters as the 2-D GSHP model. It has been rescaled to match the build specifications of the actual installation.

4.2 Calibration

To align the computer model with reality, data involving temperature, heat flow through the loop field and soil properties were combined to reproduce a known temperature profile after roughly 4 months of usage. To achieve near homogeny between the simulated and actual temperature profile, modifications were made to moisture content as a function depth. The resulting temperature profile is shown below:

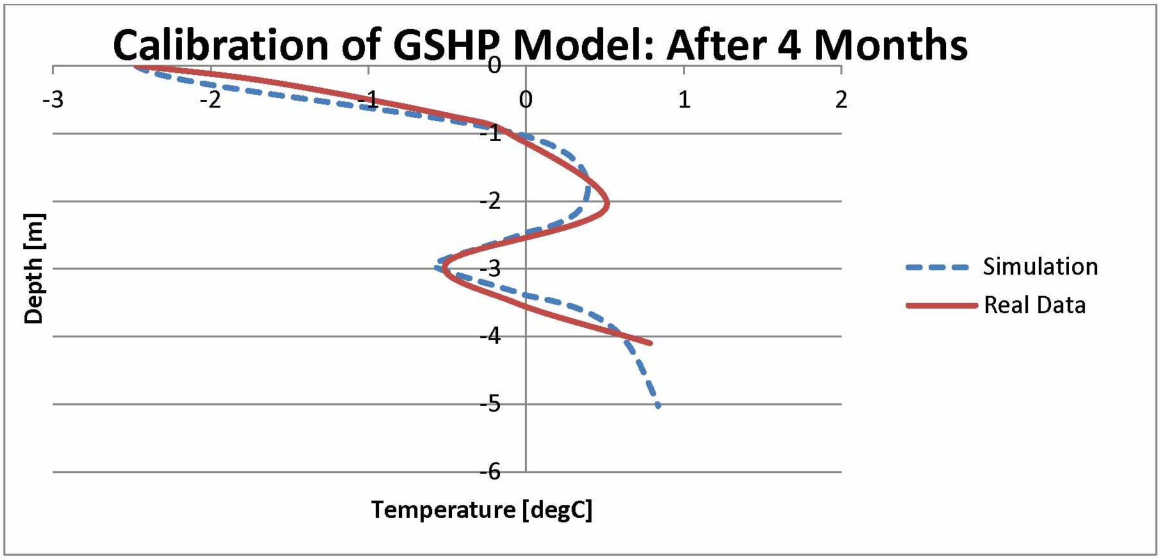


Figure 30: Calibration Run

With this calibration, a few select runs were done to investigate the long term issues that may arise with this particular field. This chapter will look at only a few different variable changes to predict the long term viability of CCHRC's GSHP. In particular, a few sets of N factors, representative of different surface treatments along with looking at the possibility of active recharge to promote subsurface temperatures.

The surface "N" factors in this chapter will attempt to emulate real world surface coverings to see how the effect the GSHP. This is duplicating what CCHRC did with their GSHP. The surface treatment is a relatively inexpensive change to the system compared to other influential factors such as bulk soil type or soil density.

Active recharge of the soil would most likely come from solar thermal collectors which would primarily be effective during the summer months. While such a system may be cost prohibitive, this analysis will strictly focus on what will be required to have a viable system after 10 years of usage. To model this recharge a simple constant influx of heat is applied to the model as the air temperature rises above freezing. This represents warm fluid being recirculated through the ground loop, warming the soil. The rate of heat in W/m is recorded in the data table.

4.3 Results

For the runs taken the temperature profile both above and below the loop is displayed. The table below shows the raw outcome for the 6 trials that were run. The "N" Factors show a rough estimate for each surface covering. While there may be significant error with these estimations. In the end, my data shows that their influence is rather small compared to the requirements of the GSHP.

Surface Treatment	N-Factor Thawing	N-Factor Freezing	GSHP Peak Heat [W/m]	Summer Recharge [W/m]	Yearly GSHP Heat [kWh/Yr]	Yearly Recharge [kWh/Yr]	Failure Point [Yr]
Grass	0.9	0.5	23.3	0	35000	0	2.1
Light Sand	1.2	0.6	23.3	0	35000	0	2.1
Dark Gravel	1.5	0.8	23.3	0	35000	0	2.1
Dark Gravel	1.5	0.8	23.3	10	35000	14688	3.2
Dark Gravel	1.5	0.8	23.3	15	35000	22032	6.2
Dark Gravel	1.5	0.8	23.3	20	35000	29376	10+

Table 5: CCHRC GSHP Forecast

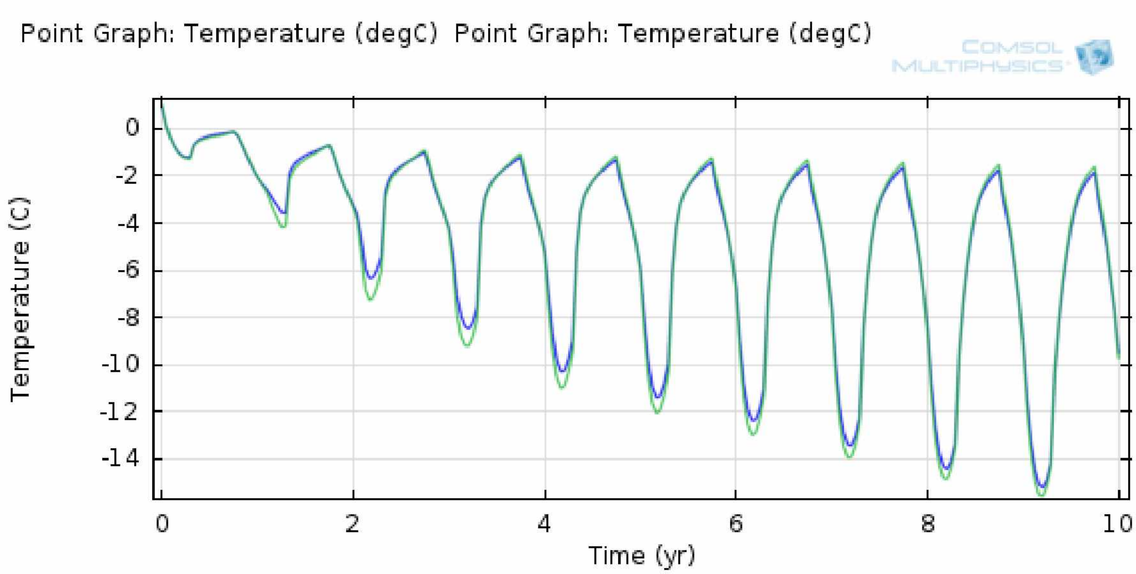


Figure 31: CCHRC Loop Temperatures, Grass with No Recharge

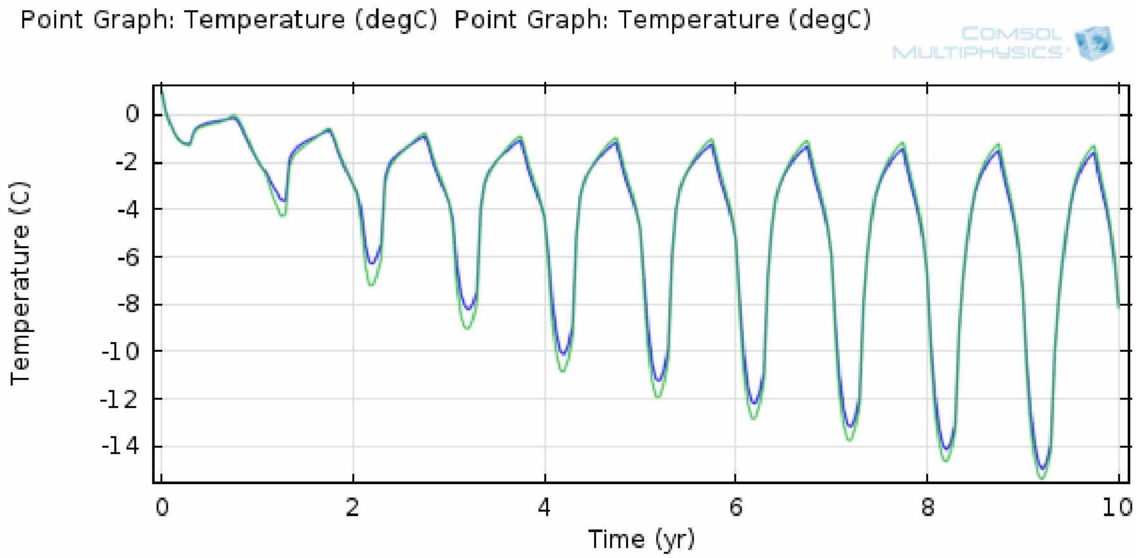


Figure 32: CCHRC Loop Temperatures, Light Sand with No Recharge

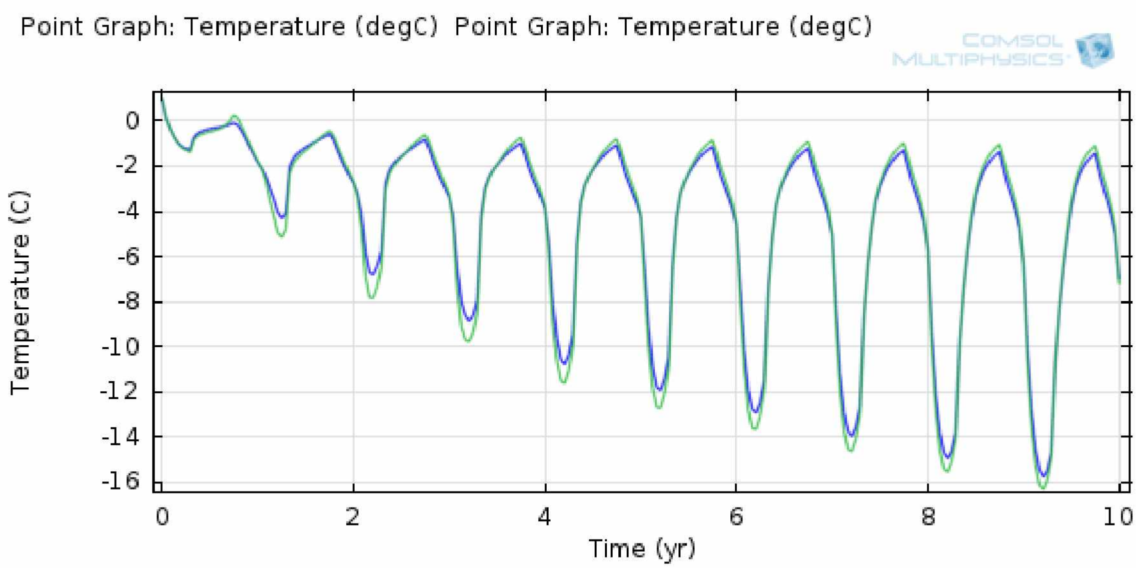


Figure 33: CCHRC Loop Temperatures, Gravel with No Recharge

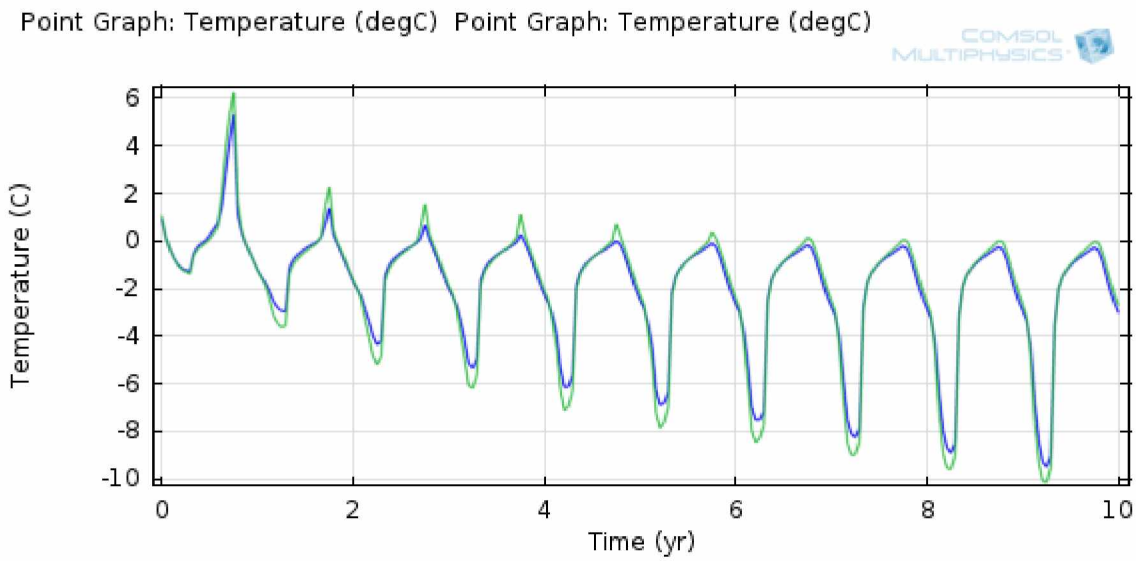


Figure 34: CCHRC Loop Temperatures, Gravel with 10 W/m Recharge

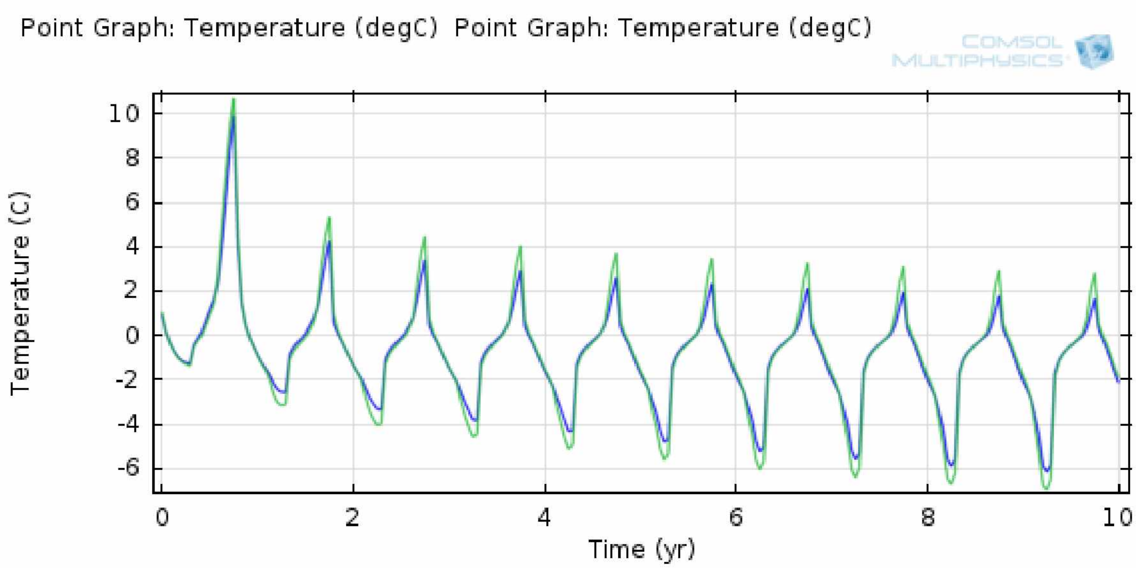


Figure 35: CCHRC Loop Temperatures, Gravel with 15 W/m Recharge

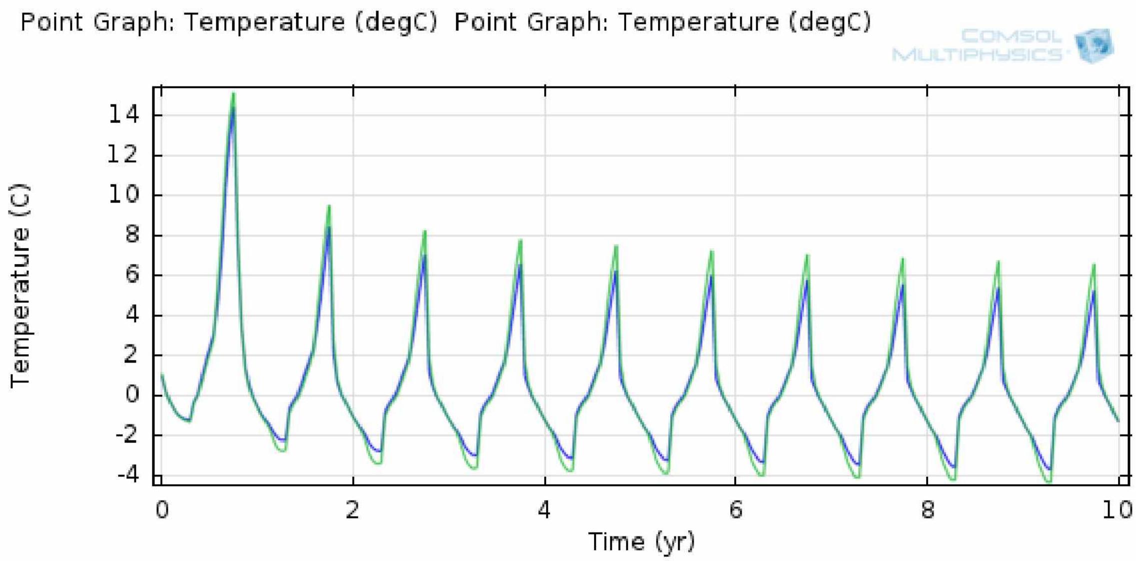


Figure 36: CCHRC Loop Temperatures, Gravel with 20 W/m Recharge

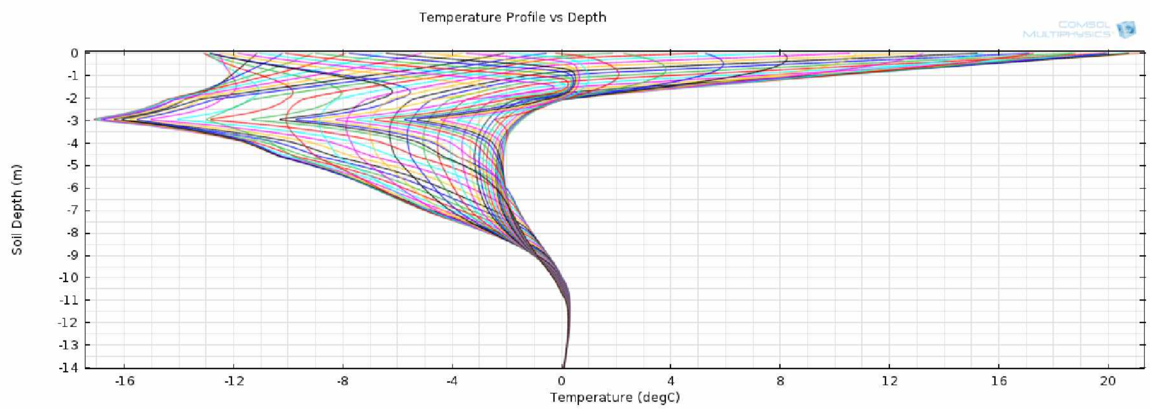


Figure 37:CCHRC Temperature Profile, Gravel with No Recharge, at 10 Yr

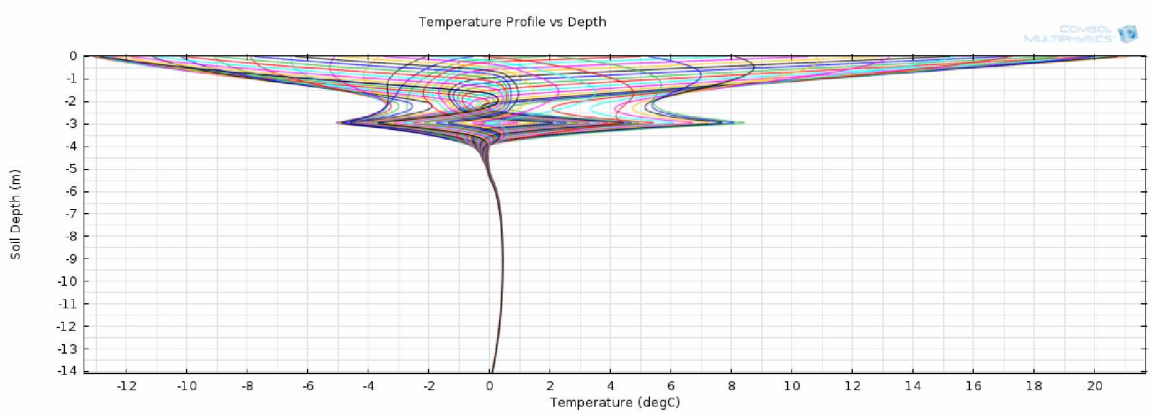


Figure 38:CCHRC Temperature Profile, Gravel with 20W/m Recharge, at 10 Yr

4.4 Observations

After these simulation runs it is very clear that that some kind of thermal recharge is required for a GSHP such as the one constructed for CCHRC. While ground covering did slightly affect the thermal regime of the soil column, the effect was just too small. By looking at table 5, it can be seen that roughly three quarters of the energy absorbed by the ground loop would needed to be forced back into the soil for the system to be viable.

CHAPTER 5: CONCLUSIONS

As seen in these simulations, soil properties can have a large effect on the sustainability of a GSHP. This is especially true in areas like Fairbanks where the climate is marginal for a passively recharged system. In almost all cases, these simulations suggest that a passive system will start to develop permafrost below the loop. This will inevitably lead to depressed temperatures and require greater work to extract useful heat from the soil column. This hurdle is not insurmountable though. Proven technology such as an active recharge system may prevent issues with the development of permafrost. This would add cost to such a GSHP project and may make a project cost prohibitive. Mitigation may also be possible with better siting and usage of good soil geology. Higher moisture content soils as well as higher density soils would create more suitable conditions for the system to run efficiently. Additionally, using a surface treatment that promotes heat transfer in the summer months and retards it in the winter months could also have a significant impact on soil temperatures around the loop field as suggested in my simulations. Applying this to a real world system would also help it function long term.

From here many further questions could be explored. The models utilized for this project leave a lot of room for improvement. Many simplifications were for made expedience and homogony between test runs. Instead of “N” factors, layers of snow, organic coverings or specific engineered surfaces could be integrated. Each of the options could theoretically improve the realism to this model, but it would add significant complexity.

Beyond the computer simulation, more real life data could be utilized for analysis. As of the writing in the report, less than half a year's data from CCHRC's GSHP was available to compare with the computer model. In addition, no summer data is available in conjunction with the running system. A year or two of complete data would go a long way to building a more accurate model.

REFERENCES:

Cold Climate Housing Authority, CCHRC RTF Ground Source Heat Pump Design Documents. CCHRC, Fairbanks, Alaska. 2013.

Kersten, M.S. 1949. *Thermal Properties of Soils.* Engineering Experiment Station Bulletin 28, University of Minnesota, 227 p.

Kersten, M.S. 1963 Thermal properties of frozen ground. In: *Proceedings, 1st International Permafrost Conference,* Purdue University, West Lafayette, Indiana.

Smith, D.W. *Cold Regions Utilities Monolith, Third Ed.* ASCE, Reston, Virginia, 1996. Print.

Western Region Climate Center. *Alaska.* NOAA. Mar. 1, 2014. Web